# Integrated "TBA-IN" testers and their impact on the reliability of telecommunications AC / DC power systems

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**Abstract:**

The article presents the results of scientific research and manufacture aimed at achieving the required level of reliability of power systems operated in telecommunications facilities. The results of research and works in the field of unique measurements of the available capacity of VLRA battery, which are an important element of the ICT system in telecommunication facilities, are presented. The TBA-IN15 testers are integrated partial AC / DC power supply with 40-160 Ah batteries and increase the life and reliability of the system, as well as powered ICT systems.

**Keywords:** power systems, reliability of power systems, batteries efficiency test

## Introduction

In the process of operation of ICT devices and networks, their reliability, understood as a property consisting in the proper performance of tasks, mainly consisting in the provision of ICT services, is becoming increasingly important. It is assumed that reliability is the ability of ICT devices and networks to provide services in specific operating conditions [1, 2, 3, 4, 5, 6]. Reliability is associated with durability. In relation to standardization work, durability is defined as the ability of a functional unit to perform the required function under given conditions of use and service, until reaching the condition [4].

Referring this statement to a functional unit, which is either a device or a tele-informatic network, the limit state should be interpreted as the period of end of their life, caused by unprofitability for technical, economic or other important reasons.
Analysis of source materials [7, 4, 8] and practice shows that durability talks about how to ensure the reliability of ICT devices and networks in specific operating conditions.
On the other hand, maintenance means their monitoring, diagnosis, care and inspection, as well as other related activities, including administrative activities. In practice, maintenance is also referred to as serviceability [5], which usually comes down to activities performed after a device or system is damaged.

ICT networks are the basis for the functioning of modern information civilization, and the services they provide are conducive to the development of modern society. Research carried out in recent years indicates that among the elements of ICT networks, radio access systems are developing the fastest, mainly as cellular networks. They are located in telecommunications facilities, supplies by systems with redundancy equipment, and their number in Poland is estimated to be tens of thousands [9, 8, 10].

Telecommunications equipment, including their power supply systems, are designed for considerable service life - usually 25 years. But any technological change results in the appropriate replacement of transmission devices, transceivers or devices for remote supervision and management. This means that the reliability of the ICT network and its services depends, to a large extent, on the reliability of the AC / DC power system.

**AC/DC power systems for telecommunications facilities**

Telecommunications devices are powered by 48 VDC [14]. Due to this fact, the basic element of the AC / DC power system are the power rectifiers - PS (see Fig. 1 a). Generally speaking, these rectifiers, powered from the AC power network supply telecommunications equipment "R" and charge "B" batteries. "B" batteries take over the power supply to devices during AC power outage.

The current AC / DC power system performs in the operating modes:

- **floating mode** - the basic AC / DC operating mode, in which the DC energy receivers are powered from rectifiers (approx. 54 V), and the batteries in a fully charged are connected in parallel with the rectifiers and receivers to the output of the power system and draw a small current , to supplement loss due to self-discharge;

- **battery mode** - occurs automatically after a loss of AC mains voltage, in this mode DC energy receivers are powered from the accumulator battery until the AC voltage will recover or the battery is discharged. (Batteries should be disconnected from the load if a voltage is below 43.2 V by the RGR deep discharge disconnector, if the power system is equipped with it);

- **battery recharge mode -** occurs automatically after AC mains voltage recovery (and after switching on the RGR, if was disconnected); charging takes place at an elevated (as recommended for a given type of battery) voltage, usually not higher than 57.6 V, and after reaching this voltage and the set time, the system automatically goes into the floating mode;

- **battery efficiency test** - consists in partial discharge of all batteries connected to the system, for this purpose the voltage of receivers is reduced to a value that forces the DC supply from batteries , but maintaining an energy reserve (approx. 50%) in case AC power failure; this test detects battery blocks that exhibit below average efficiency, but does not provide knowledge of actual block capacity.

Real AC / DC power systems (see Fig. 1b) contain [8] additional components whose task is either to facilitate service and maintenance operations, or to improve the reliability of the power supply system. In the offered power systems, except for batteries of course, all elements are easily replaceable during operation and the device are durable, small, light and easy for long-term storage.

In the power system, the main modules supplying energy receivers "R" are redundant (type N + 1, where N is the minimum number of elements required for the proper functioning of the power system). The analysis shows that a greater number of elements results in a greater likelihood of failure, while for the failure of only one element (even for a single-phase AC network) the power system will not lose the basic functionality and still supply devices with power. But until the repairs take place, at most there will be a limitation of its functionality.

Source documents [11, 12, 13, 14, 15, 8, 10] and own research allow to create this description of the component functions of a modern telecommunication AC / DC power system.

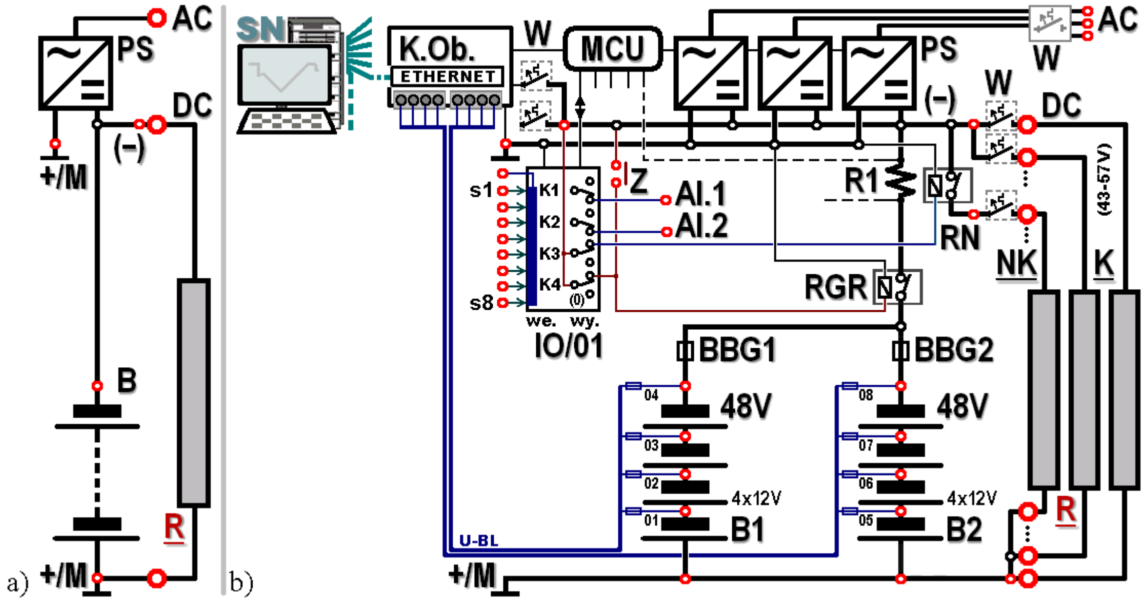


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Fig. 1. Block diagram of the AC / DC power supply system: a) in general; b) example of real solution

**"PS" rectifiers** can be powered from different phases of the AC network (or from different transformer substations) and possibly from a power generator - they convert AC voltage from to DC with the required current and voltage. Several identical parallel modules will cooperate in the power system with such current efficiency that will ensure the operation of "R" energy receivers and charging "B" batteries, also when one of them will be off (e.g. failure, maintenance).

**"B" ("B1", "B2") batteries** are a backup power source in the system, and their main parameter is the battery backup time, i.e. the time during which the battery should power the receivers in the event of an AC loss. Due to the required reliability and the ability to control the battery when disconnected from the system, the power system uses at least two identical parallel batteries (usually 48 V lead-acid type VRLA). The batteries work with floating voltage 54 V and are usually made of 4  12 V blocks.

**"R" DC energy receivers** (i. e. telecommunications equipment) in AC / DC power systems are devices directly supplied with DC voltage (36 - 65 V required range ) or 230 V / 50 Hz alternating voltage produced from the guaranteed DC voltage of the power system. In the power system, two groups of energy consumers are often distinguished - critical K and non-critical NK. The first one includes those that in case of AC power outage must work for as long as possible. The second group includes those that can be turned off if AC power outage occur either immediately or for power outage above a specified time.

**Overload protection**. Main fuses of batteries "BBG1" and "BBG2" allow safety disconnection of each battery from the power rail for maintenance or in the event of either an overload or short circuit on the power rail. "W" circuit breakers can either disconnect the network in the event of an overload or manuals disconnect the AC network and "R" energy receivers. "W" circuit breakers can either disconnect the network in the event of an overload or manuals disconnect the AC network and "R" energy receivers.

**Current shunt "R1".** Resistor shunt (sometimes an LEM sensor is used) required to measure speed when charging or discharging the battery.

**The "RGR" low battery disconnector** is an optional element of the power system. To protect the batteries against destructive deep discharge, the RGR disconnect them from the "PS" rectifiers and "R" receivers at a battery voltage of about 42.2 V.

**The "RN" disconnector** of non-critical receivers can extend the operation of the power supply system in the event of prolonged power outages. Immediately (in the event of an AC power failure) at the command of the "MCU" control module or "K.Ob" object controller, it can permanently or periodically disconnect direct current receivers they are not critical to the operation (heating, lighting, etc.).

**The "MCU" control module** (power system controller) manages the operating mode of the servomotors and the rectifier output current and controls the parameters and function of the system, rectifiers and batteries. Most often it uses special "IO" input / output cards (modules). The control and monitoring functions of the "MCU" are implemented in accordance with the recommendations issued either locally or remotely, in cooperation with a centralized management system via modem, Ethernet, Web or SNMP. The control module can be turned off if necessary (i.e. failure, maintenance) - then rectifiers and batteries with the RGR disconnector must power the energy receivers autonomously.

**Specialized IO (input / output) cards** (modules) are connected to the controller and to each other via CAN bus. For example, Fig. 1b shows, the digital card "IO / 01" with signaling inputs "s1-8". It is responsible for disconnectors "RN", "RGR" and urgent alert "Al.1" and non-urgent "Al.2".

**The "K.Ob" object controller** is usually a module dedicated to remote SN monitoring of system odd. It participates in communication with the "MCU" control module, provides information about the state of the power system, batteries, telecommunications equipment, as well as door status, a picture of the interior and surroundings of the object and it can control air conditioning, door locks, lighting, etc.). The controller also provides (if this is not done by the "MCU" driver) the voltage of the battery blocks ("U-BL" in Fig. 1).

**Real battery capacity**

Batteries with a floating voltage of approx. 54 V are used [11, 13] in the analyzed AC / DC power systems. The batteries contain four blocks, with a rated voltage of 12 V and a capacity of 40 Ah to 170 Ah and weighing up to 60 kg, connected in series, wherein each block has a leak tight housing (but its "+" and "-" terminals are available) and each block is composed of 6 cells connected in series.

The nominal capacity of accumulators and accumulator batteries is designated as C or Q10, and is provided by the manufacturers for charging ten hours with a constant current, described as $I_{10C}$ or 0.1CA, i.e. as discharging fully charged batteries for 10 hours at 20°C and without exceeding the minimum voltage of 1.80 V / cell. Of course for a lower discharge current, the capacity is slightly higher, and at a high current it decreases significantly (with a current of 1CA it is about 60% of the rated capacity). The real capacity of the same battery, at the same current but at different temperatures is different (at -15 ° C, when electrochemical reactions are slower, it is 2 times smaller than at + 35 ° C).

Battery life is determined by the manufacturers in years and the number of discharge and charge cycles after which the fully charged battery or block will remain within the floating voltage, and provided that it has at least 80% of its nominal capacity [8, 16]. The service life depends on the battery type and operating conditions, where:

- prolonged operation at an elevated temperature by every 10 ° C for the rated temperature of + 20 ° C reduces the service life twice;
- large voltage spread on individual cells in the serial chain of a block or battery causes some of the cells to be permanently undercharged, and some to be overcharged, which results in their accelerated degradation;
- long-term low battery conditions lead to their sulphating, so they should be kept fully charged, which ensures the floating mode and immediate charging even after partial discharge;
- batteries are designed for a specific number of discharge and charge cycles, but with the number of cycles with 30% capacity charging approximately 10 times greater than for full discharge (100%). The number of cycles decreases strongly with increasing discharge (it is defined for 0.1CA);
- due to their serial connection, the parameters of the entire battery (voltage, capacity, internal resistance, current efficiency) is significantly affected by the worst block);
- PCL phenomenon, rapid premature loss of capacity, occurs for several percent of VRLA batteries, regardless of technology, type and manufacturer,.

**Measurement of real battery capacity**

Practice and quoted studies include that the measurement of a capacitive battery is performed by its discharge (capacity is the product of current and time). From the user's point of view - the capacity available at the current given to energy receivers at a given location is interesting. However, the value obtained in this way is difficult to compare (devices have different power consumption), the battery supplier takes into account complaints documented by testing at rated current, and discharging the battery with a non-rated current strongly affects its lifetime. Therefore, to clearly determine the actual capacity, it is best to discharge the battery with 10-hour current, i.e. 0.1CA. After discharging, to maintain the best condition, the battery should be immediately fully charged - preferably with a current close to 0.1CA (maximum - 2 times more or 2 times less) [17]. The result of the test is the real capacity Q expressed in ampere-hours (Ah) and the percentage of nominal capacity (Q =% C), but you can also measure the number of watt-hours (Wh) received (it is also useful). A battery in good condition generates about 5% loss, i.e. the number of ampere-hours charging the battery is 5% higher than that charged when discharged. In the AC / DC power system in a telecommunications facility, the real battery capacity can be measured using an adjustable high-power resistor, voltmeter and ammeter - by multiplying the discharge current in amperes by the time (in hours) that elapsed until the voltage drops from the battery to the recommended limit. In turn, when using an automatic resistive discharge (with recording of ampere-hours), one should only ensure immediate recharging of the discharged battery usually from a dedicated rectifier. The automation of the entire battery discharge and charging control process is ensured by portable TBA-IŁ testers and the built-in TBA-IN15 [5, 8]. However, the use of the TBA-IŁ meter requires the battery to be connected / disconnected by the personnel performing the test, using the TBA-IN15 tester - these activities are performed by specialized elements permanently placed in the power system.

The TBA-IN15 testers developed at the National Institute of Telecommunications have been subjected to detailed tests in a real facility[1]. The obtained test results are presented in Fig. 2, which shows the voltage characteristics of two different (100 Ah capacity) accumulator batteries used in AC / DC telecommunications power systems.

The test was defined with a 10 A discharge and charge current, a maximum of 85% of rated capacity taken, and the lowest possible worst block voltage of 10.8 V (1.80 V / cell or 43.2 V for the entire battery). Data obtained in the course of tests from the TBA-IN15 meter, installed in the already operating AC / DC power system, is presented in Fig. 2a, data obtained in a dedicated power system Fig. 2b, respectively.

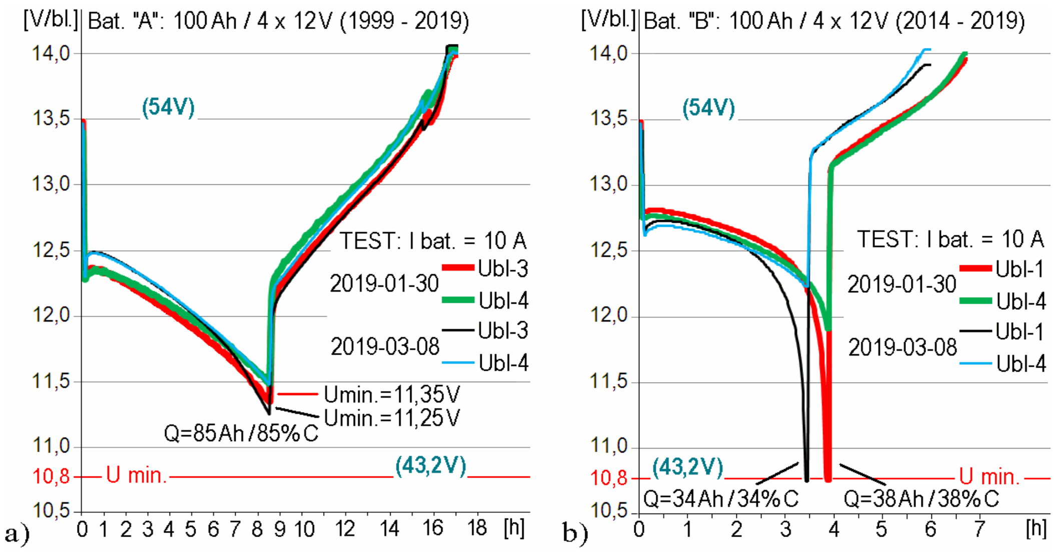


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Fig. 2. Voltage of blocks of the tested battery: a) fully functional; b) with the PCL effect

Presented results of tests were obtained in real conditions of battery use.

The battery from Fig. 2a has worked in an air-conditioned power system for 20 years (there is no detailed knowledge about the number and depth of battery discharges). The battery is in a very good condition because its real capacity is above 85% of rated and the difference between block voltages is small (the worst and best block voltage is shown there) during 2 tests made

[1] The research was led in 2018 and 2019. The research covered, among others Telzas power system and Benning power system type SBE2000SL, adapted to work with TBA testers.

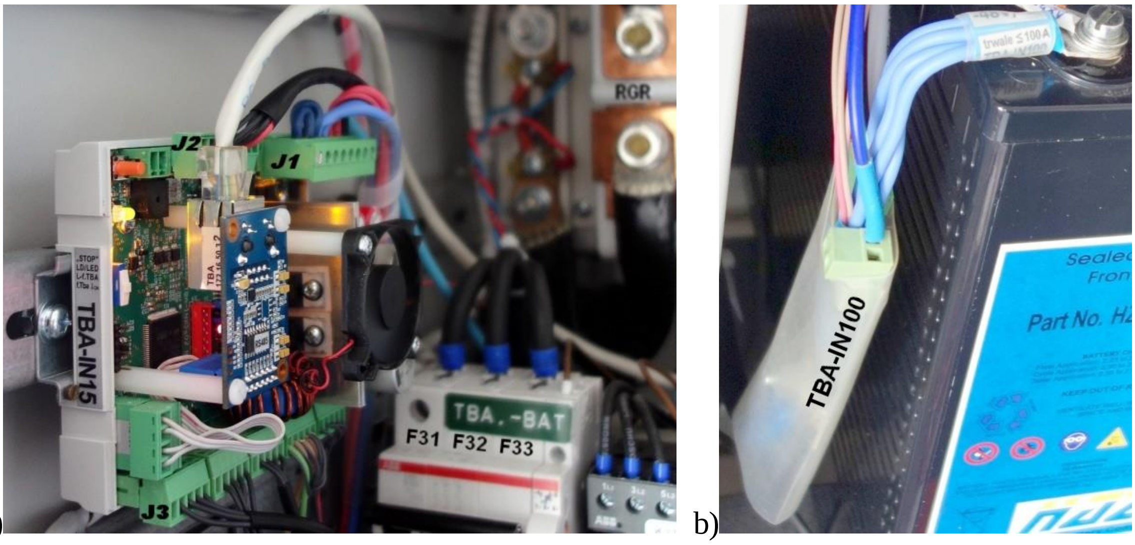
with a 2 month gap. The tested battery working in parallel, like the second battery, meets the typical requirements for a back-up energy source (Q> 80% C).

The battery shown in Fig. 2b worked without air conditioning in the NIT laboratory. The battery usually operated with its floating voltage. Within 5 years it was discharged about 20 times to the limit voltage of the "worst monoblock", mainly by 0.1CA, but several times by 0.2CA or 0.05 CA. After 2 years of use, a decrease in capacity was noted. The two tests led to real capacity below 40% of the rated value in 2019 and we can a observe the fast degradation of the first block of this battery and a good condition of other blocks.

**Integrated TBA-IN15 "real battery capacity" tester in the AC / DC power system**

The integrated TBA-IN15 "real battery capacity" tester is permanently installed in the AC / DC power system. It exchange information with the supervision system (SN) via the "Modbus RTU" protocol, via an RS485 or Ethernet interface, usually via the system's object controller. It allows, on command of the supervision system, to start discharging and charging the indicated battery with the set current and end after reaching the final voltage (or after a set number of ampere-hours). During discharging - the energy drawn from the battery is transferred to direct current receivers (with efficiency at least 95%), relieving the "PS" rectifiers. It measures the block voltage of all batteries in the power system, and when testing the indicated battery shows the actual current and the number of ampere-hours (and watt-hours) received and delivered. It can work with a maximum current of 16 A (which is a discharge current of 0.1CA battery 160 Ah) and can work with a maximum of five batteries. Testing each battery, usually once a year, takes about 24 hours. It should be initiated when the AC network shutdowns are not expected. In the period between tests, switching the meter off or changing it has no effect on the power operation [8].

Presented in Fig. No. 3a TBA-IN15 meter, measuring 72 x 105 x 95 mm, and can cooperate with dedicated battery disconnectors , measuring 40 x 90 mm, see Fig. No. 3b [10].




a) b)

*Author's photo*

Fig. 3. Views of the AC / DC power system: a) TBA-IN15 tester , b) TBA-IN100 - battery disconnector

Their basic technical parameters of the tester and disconnectors presented in Table No. 1.

Table 1. Basic parameters of testers with disconnector

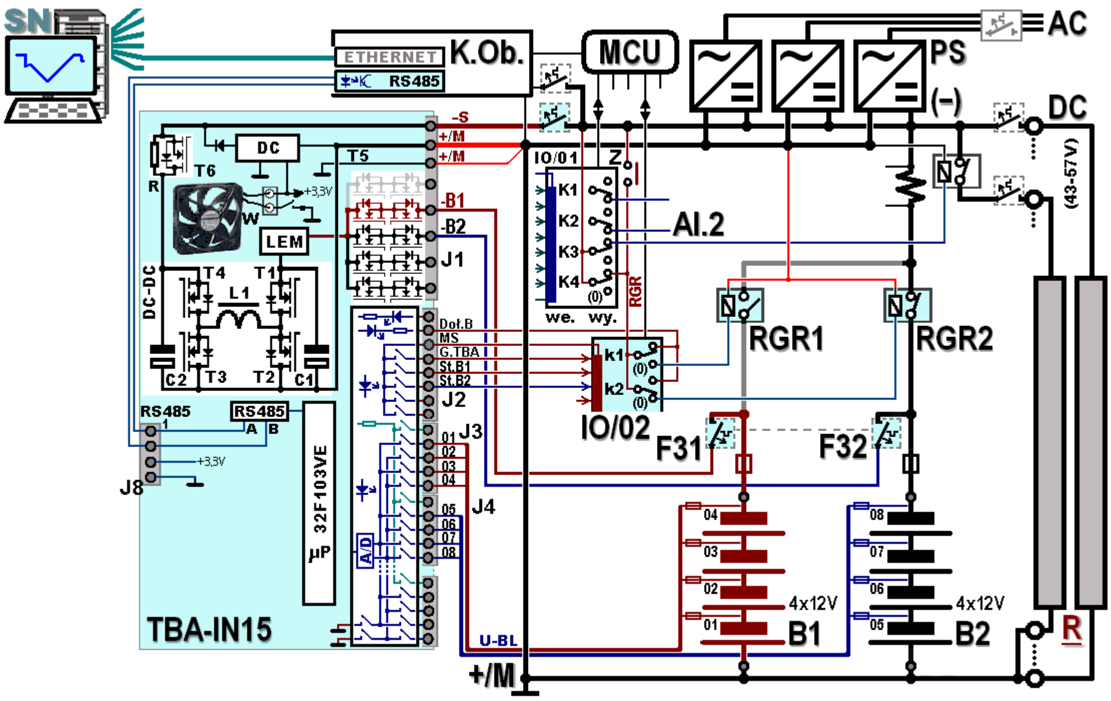
| | **TBA-IN15** | *TBA-ST (other versions)* |
|---|---|---|
| Number of supported battery | 2 – 5 | 2 – 3 |
| Battery discharge / charging current | 16 A | 50 A |
| Capacity of checked batteries | 40 – 165 Ah | 40 – 500 Ah |
| Accuracy of measuring voltages, current, capacity | ±1% | ±1% |
| Is the (RGR) battery disconnector part of the power system * | YES | YES |
| TBA-IN100 battery disconnector (max. permanent current) | TES (180 A) | NO |
| Exchange information with (by Modbus RTU protocol) | RS485, Ethernet | |
| Case and mounting the meter in the power system | DIN rail | half size of 1U cassette |

* for selected types from current AC / DC power system production

*Own study*

TBA-IN100 battery disconnectors, depending on the version, can be installed in battery circuits protected with 125 A or 160 A or 200 A fuses. The power lost in the disconnector during typical operation is below 0.3 W, but with a maximum permanent current is approx. 8 W ( the internal resistance of disconnector is well below 1 mΩ).

The research shows that the TBA-IN 15 tester is most preferable installed in new, dedicated (adapted by the manufacturer) AC / DC power systems (see Fig. 4)[2].




*Own study*

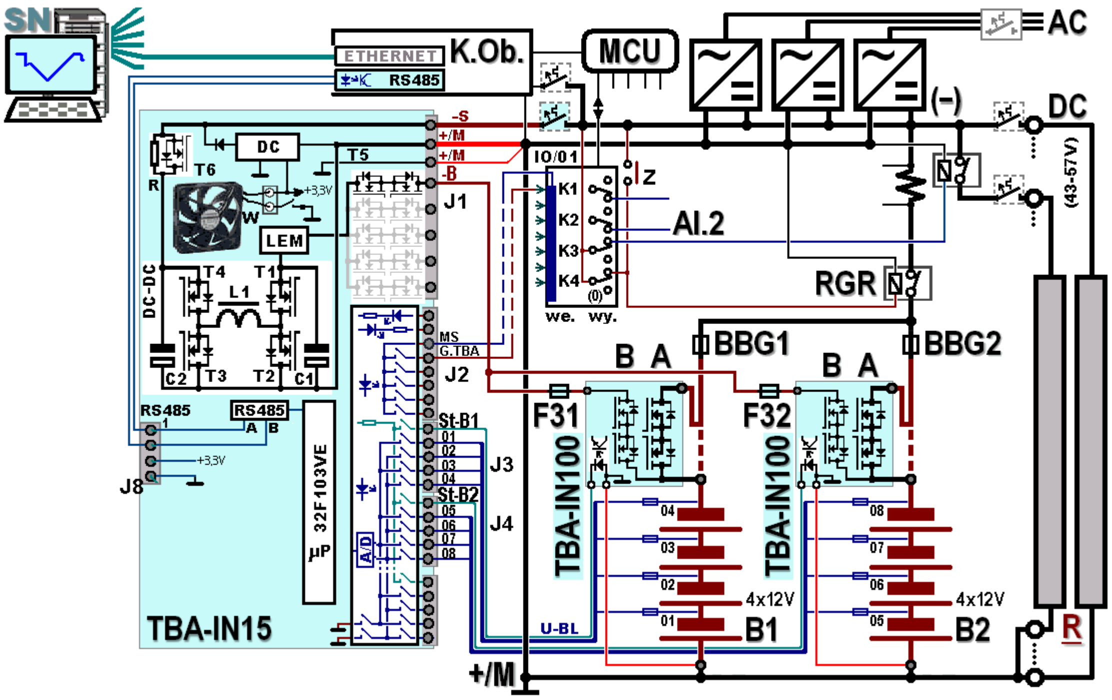
Fig. 4. AC / DC power system with built-in TBA-IN15 tester (when testing the B1 battery)

[2] Tests were carried out in AC/DC power system, manufactured and adapted by Benning, based on a contract between Benning and Telzas power system manufacturers

The adaptation consists of adding individual disconnectors ("RGR1" and "RGR2") for each battery instead of the common "RGR" - controlled from the outputs of the additional "IO / 02" digital card, on which inputs the "G.TBA" tester operation signal is given and signal to request disconnection of the "B1" battery ("St.B1" signal) or "B2" battery ("St.B2" signal) from the system. In addition, the negative poles of the battery are connected through the current protection "F31" and "F32", with the individual current inputs "-B1" and "-B2" of the tester. The similar solution can be used for testing 2-4 batteries.

The TBA-IN15 tester can also be installed in any AC / DC power system but dedicated TBA-IN100 battery disconnectors should be added (see Fig. 5). The TBA-IN100 disconnector module should be installed in the current lead of each battery in such a way that the lead disconnected from the negative battery terminal should be connected to its input, and the disconnector output lead should be screwed to this terminal.

Disconnector "A" transistors will be actuated (cause connecting the battery to the power system) after connecting the disconnector's "ground" wire to the positive battery terminal (i. e. ground of power system). The control signal from the tester (on either the "St-B1" or "St-B2" cable) will disconnect the selected battery from the power system (by turning off the "A" transistors) and connect it (by turning on the "B" transistors) to the tester current input. The solution can be used for tests with 2 - 5 batteries [3].




*Own study*

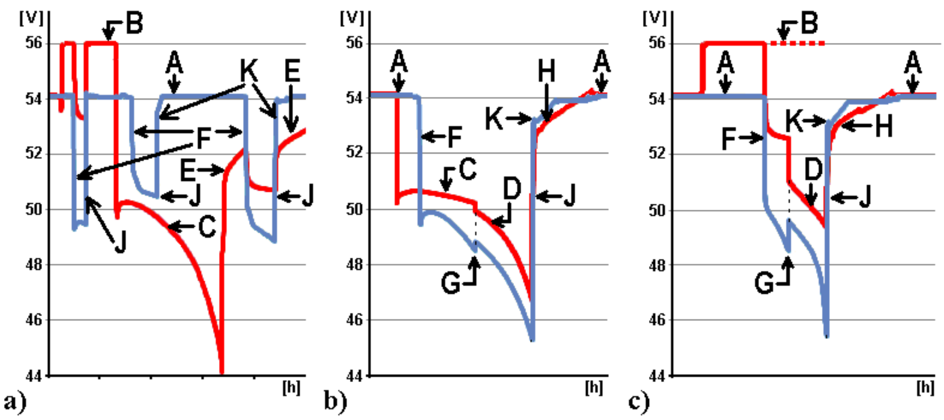
Fig. 5. TBA-IN15 tester, with TBA-IN100 disconnectors, in AC / DC power system

[3] The tests were carried out for the AC / DC power system manufactured by Benning and Telzas and used by mobile network operators.

### Impact of the TBA-IN15 tester on the telecommunications facility power supply system

The study shows that after installing the TBA-IN15 tester in the AC / DC power supply system and connecting it to the "SN" supervision system (e.g. to the N!BoX system from NetWorkS!), a reliable battery image is obtained - without visiting telecommunications facilities . The results are collected and processed in the monitoring system allow you to find batteries that require urgent replacement, identify batteries with a deteriorating condition and require replacement in the near future, as well as those that are likely to remain functional for a long time. Based on the long-term results, you can evaluate the quality of each type of battery - and we can take this into account in future purchases.

As mentioned, the battery is disconnected from the power supply system for the capacity measurement. If during the test there is a loss of AC voltage, such a battery, due to voltage differences, should not be connected directly with the other battery and with "R" energy receivers. Therefore, the TBA-IN15 tester will ensure the safety transfer of energy contained in the tested battery to the system, to the DC energy receivers of the power system in the event of a loss of AC network voltage. The result of this research is presented in Figure 6.




*Own study*

Fig. 6. Power AC outage while testing the battery disconnected from the power system:
(a) short-term interruptions during "B" equalization, "C" discharge and "" E "recharge; b) long-lasting AC outage during battery discharge, c) long-lasting AC outage during battery recharge.

Notes:
A = battery floating voltage "B1" and "B2" (load current is 25 A);
B = scheduled "equalization" of "B1" batteries;
C = scheduled "control discharge" of the "B1" battery (with 10 A current);
D = the mode of "supporting the power system" with energy from "B1" batteries (with 16 A current);
E = "Recharge" after testing the "B1" battery capacity;
F = voltage on the power system's "-" rail (and "B2" battery voltage);
G = voltage on the "-" rail initiating "support of the power system" with energy from the tested battery;
H = charging the "B1" battery after AC power recovery, before joining the system;
J = voltage on the "-" rail, AC power return indication;
K = charging "B2" battery after AC power recovery.

As shown in Fig. 6a, with short-term AC power outages (manifested by a slight voltage drop on the "-" rail of the power system), the scheduled battery test is continued (with short breaks during charging). If during the discharge of the battery (Fig. 6b) the voltage on the "-" rail of the power system drops below 48.5 V, then the tester also passes into " power system support " mode - working with its maximum current it transfers energy from the disconnected battery to the "-" rail of the power system. If, while charging the battery (Fig. 6c), the voltage on the "-" rail of the power system drops below 51 V, then charging (here - equalizing) is suspended, and when it drops below 48.5 V, the meter goes into "power-assist" operating mode (it transfers energy from the battery to the "-" rail of the power system).

Because each battery is charged individually by the TBA-IN15 tester (after disconnection from the system) to the given voltage - it is possible to operate the power system with the different types of batteries, e.g. VRLA battery + lithium battery, and it is safe for batteries and R energy receivers.

In this system, if short interruptions in power supply occur then mainly a lithium battery is discharged (due to the low voltage drop of the disconnected battery), but if long interruptions occur then also a VRLA batteries discharged.  Also then both batteries can be optimally recharged individually.

If TBA-IN100 battery disconnectors are installed together with the TBA-IN15 tester, they can increase the functionality of the power system. In a power system without a deep discharge disconnector, "RGR" can perform its function - either alone or (thanks to an additional input, not shown in Fig. 5) controlled from the "K.Ob." object controller. In the latter case - they will allow remote disconnection of any battery (fully charged state) from the system and connecting them to the system. This can be useful when a long break in AC power supply is expected - either to protect the battery against a long-lasting discharge, or to run overlapping telecommunications facilities when transmitters ranges overlap.

**Reliability of AC / DC power system equipped with the TBA-IN15 tester**

The TBA-IN15 tester installed in a dedicated AC / DC power system (see Fig. 4) does not affect the reliability of the AC / DC power system. Although the number of "RGR" disconnectors is increasing, damage to one of them will not affect the functionality of the entire power system (which is the case in the classic solution, as on  Fig. 1b). Disconnecting the battery is controlled by the "MCU" power system controller, if a command is received from  the TBA-IN15 tester. The conducted tests[4] indicate that a dedicated power system with a built-in tester meets all the requirements for AC / DC telecommunications facilities.
The TBA-IN15 tester installed together with the TBA-IN100 disconnectors in an already used AC / DC power supply system (see Fig. 5) slightly reduces its reliability - especially the case with frequent long-term operation during "battery-assisted operation" when a significant current flows through the disconnector (always high temperature accelerates electronic components degradation). In the "floating" and "re-charging" modes, which account for over 99% of the operating time of the TBA-IN100 disconnectors, current and output power are irrelevant. In practice – the design of analogous to MOSFET TBA-IN100 transistors, commonly used "disconnectors" in BMS (Battery Management Systems) ensure safe operation of even the largest lithium batteries, also in the most critical applications (e.g. aviation).

[4] This is confirmed by the results of real tests (experiment) carried out at Benning SBE200SL power system with integrated TBA-IN15 tester [8].

The TBA-IN15 tester design is similar to the "MCU" power system controller and operate mainly with small power consumption. The tester works with high currents only about 1% of the time (when the inverter is running). Moreover, damage to the tester will minimally negatively affect the operating of the AC / DC supply system (because the tester may request disconnection of a maximum of 1 battery at a time, and the status is always supervised by the "SN" supervision system "). The effectiveness of the TBA-IN15 tester is high, only max. 5% of the discharge energy is lost as heat[5], at the same time, the load on the rectifiers decreases. Thus, the thermal balance of the given power system does not change.

**Summary**

The use of TBA-IN15 "available battery capacity" testers in dedicated power systems and in power systems supplemented with TBA-IN100 battery disconnectors significantly increases the reliability, availability and durability of the entire power supply system of small, unsupported telecommunications facilities[6].

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[5] all known solutions of similar testers lose about 20% of energy from a discharged battery.
[6] The solution has been tested by NetWorkS in several facilities of few telecommunications operators. The study confirmed the legitimacy of implementing this type of solutions to achieve the higher required level of reliability of VRLA batteries and ICT equipment of the AC / DC power systems.

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