AUTOMATION OF BATTERY ASSEMBLY TECHNOLOGY AS A METHOD OF INCREASING EFFICIENCY OF RENEWABLE SOURCES OF ENERGY FOR REMOTE AND HARD-TO-ACCESS OBJECTS

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Abstract. *To date, the using of renewable-energy power plants provide a real opportunity to improve the technical and economic indicators of local power supply systems in remote and hard-to-reach areas of the country. Production and use of power storage units that meet the requirements of maintenance, safety and economy during its lifetime in autonomous power plants in this regard become most effective from the point of view of practical implementation. With the significant progress of supplies for technical accumulation an important technological solution is the high quality selection of electric accumulators in batteries during the production of energy storage devices (batteries). Developed by the Scientific and Technological Center «ANK» automated battery assembly technology allows to select individual elements (accumulators) with any degree of identity of the initial parameters. The battery testing methods used in the assembly process make possible to predict their behavior in the operation even at the production stage of the battery, to identify trends in degradation processes and hidden internal defects. This proposed approach to the creation of power storage units is a cost-effective since, along with significant production costs, it will substantially reduce labor and depreciation during the lifetime of power plants*.

Keywords: renewable energy sources, autonomous power station, power storage unites, rechargeable batteries, battery assembly technology

Currently, environmental problems and limited hydrocarbon reserves make us to look for new types of energy resources and for new energy supply technologies for consumers. The problems of power supply to remote and hard-to-access zones, where the cost of electricity is many times higher than the current centralized tariffs are particularly acute. This is due to the high cost of fuel, the need for frequent repairs, the limited operation of traditional power plants in time, the duration of the transportation of fuel, the limited timing of the seasonal delivery and the multi-link supply chain [2].

The use of power plants that convert and accumulate the energy of the sun, wind, water (renewable energy sources) creates a real opportunity to improve the technical and economic indicators of local power supply systems. The experience of Russian and foreign research groups shows that the combined use of renewable energy sources and energy storage in an autonomous power supply system is a cost-effective way of energy supply to consumers [3]. This led to the battery progress, which made them more compact, safe, reliable and commercially available [4]. As a result, the selection of an adequate technical means of accumulation with a long service life, that meets the requirement of maintenance-free, which allows not to maintain batteries for a long period of time, reduces labor and material costs during the operation of the power plant. It becomes an urgent direction in the development of the autonomous electric power industry.

The basic principles of maintenance-free, applicable to most batteries, both alkaline and acid, with aqueous electrolytes can be considered on the example of a nickel-cadmium (Ni-Cd) electrochemical system.

The main current-forming process occurring on the positive oxide-nickel electrode in the charge-discharge cycle of the battery corresponds to the reaction:

$$Ni(OH)_2 + OH^{-} \rightleftarrows NiOOH + H_2O + e^{-} \quad (1)$$

At the same time, an electrochemical reaction takes place on the negative electrode:

$$Cd(OH)_2 + 2e^{-} \rightleftarrows Cd + 2OH^{-} \quad (2)$$

When the degree of battery charge is more than 50% on the positive electrode, in parallel with the main reaction, a side process of oxygen evolution begins, which part of the energy spent on charging the battery.

$$2OH^{-} \Rightarrow 1/2O_2 + H_2O + 2e^{-} \quad (3)$$

Upon reaching 100% charge of the active mass of the negative electrode, hydrogen gas is released on its surface:

$$H_2O + e^{-} \Rightarrow OH^{-} + 1/2H_2 \quad (4)$$

When choosing the type of chemical current source (CCR) for energy storage devices used in renewable energy-based power plants, it is important to take into account both the technical part: the operational characteristics and design features of the batteries, and the economic component: production costs and depreciation charges. In this case, it is necessary to consider not only the initial costs of acquiring a battery, but also the total costs for the entire period power plants operation. The most cost-effective option in terms of initial costs is the design of the battery, providing for the equivalent content of positive and negative electrode masses that determine the capacity of the battery. However, this type of CCR, in addition to the need for additional energy costs when charging the battery, does not provide for the possibility of its maintenance free. Removing the full capacity requires recharging the battery, during which the electrolyte decomposes with the release of both oxygen and hydrogen (Fig. 1a), the loss of which must be periodically replenished during battery maintenance.

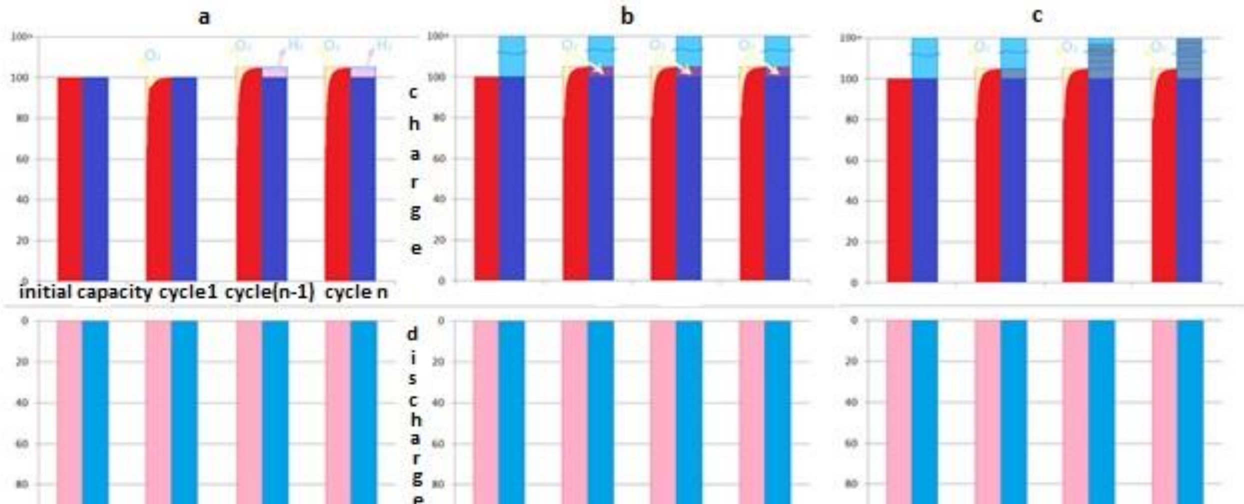

Figure 1 Balance diagrams of electrode reactions in a nickel-cadmium battery. Decoding of color designations: 1 - charging capacity of the negative electrode; 2 - charging capacity of the positive electrode; 3 - discharge capacity of the negative electrode; 4 - discharge capacity of the positive electrode; 5 - stock of discharged active mass of the negative electrode; 6 - charging capacity of the positive electrode spent on the release of oxygen; 7 - charging capacity of the negative electrode spent on hydrogen evolution; 8 - charging capacitance of the negative electrode spent on the absorption of released oxygen; 9 - the residual amount of the charged active mass of the negative electrode.

To solve the problem of maintenance freeness, 20-30% of the excess capacity of the negative active mass relative to the positive one is laid in the battery design. This principle is used to create sealed batteries in which the oxygen released on the positive electrode enters a chemical reaction with the reduced (charged) active mass of the negative electrode:

$$1/2O_2 + 2Cd + H_2O \Rightarrow Cd(OH)_2 \quad (5)$$

At the negative electrode, hydrogen is not released until the negative electrode mass is fully charged, which is not achieved in the battery charge modes (recharge level) set by the manufacturer (Fig. 1b).

Subject to normal operating conditions with a controlled level of overcharge, this model eliminates the possibility of electrolyte loss caused by the process of gas evolution from the battery, and, accordingly, the need for battery maintenance during its long-term operation.

However, the oxygen released on the positive electrode can also interact with the carbon-containing components of the active masses (the carbonization process), oxidize metal current-carrying bases of the electrodes, electrochemically recover when the battery is discharged, and exit it through the safety valve when excessive pressure inside the housing is reached. In this case, during the battery charge, part of the oxygen released is involved in reaction (5), and the irreversible loss of oxygen spent on side reactions leads to the accumulation on the negative electrode of a fraction of the active mass that is not involved in the electrochemical reaction (Fig. 1c) and, in ultimately it leads to loss of capacity.

The process of restoring the initial characteristics shown in Fig. 2 is quite realistic, but requires additional labor costs and a certain amount of time to carry out routine maintenance..

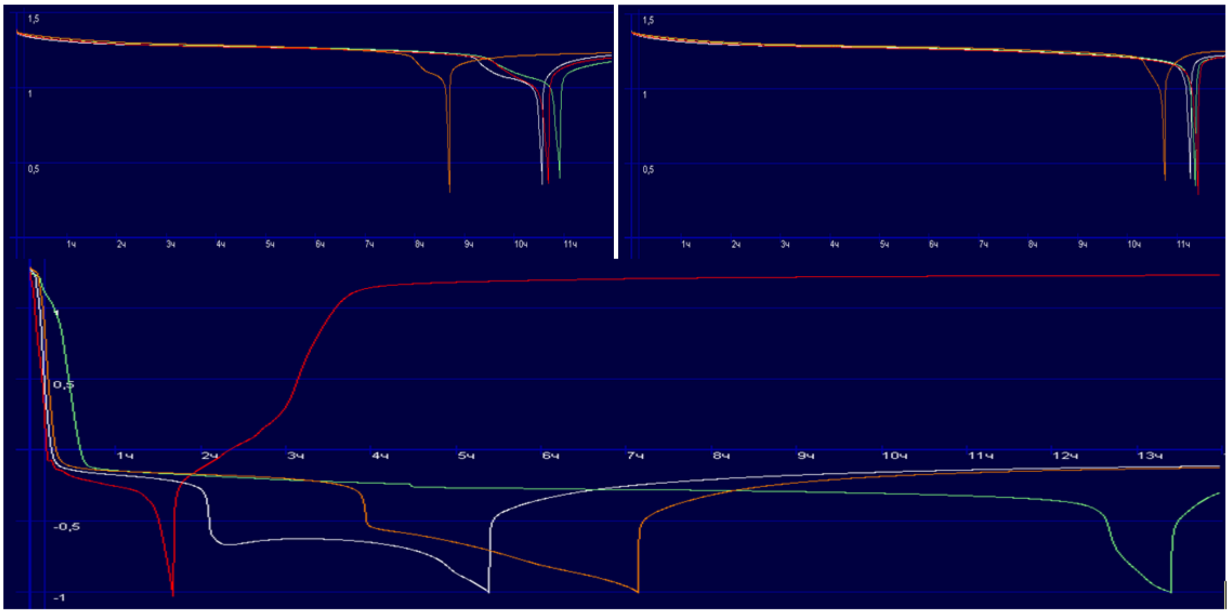

Figure 2 Conducting restoration work. Discharge curves of Ni-Cd batteries: a - before the recovery process; b - after the recovery process; c - during reconstruction

The maintenance-free requirement is quite easily feasible for individual batteries, however, when switching to a group of series-connected cells (battery), the situation may be complicated by the identity of their original electrical characteristics [5], which, in turn, during prolonged use of the battery leads to the processes shown in Fig.1c, in cells with reduced capacity. The solution to this problem is a thorough preliminary selection of cells in the battery – its manning.

In order to ensure the identity of the cells in the battery and as a result of extending its service life, RTC “ANK” LLC developed an automated acquisition technology, as well as equipment that implements this technology for both sealed nickel-cadmium batteries and other electrochemical systems, including lithium ion.

The equipment developed by the company's specialists allows the selection of cells with any degree of identity, setting the optimal level of the final charging voltage and the permissible spread of the discharge capacity in a given interval of the final discharge voltage (Fig. 3).

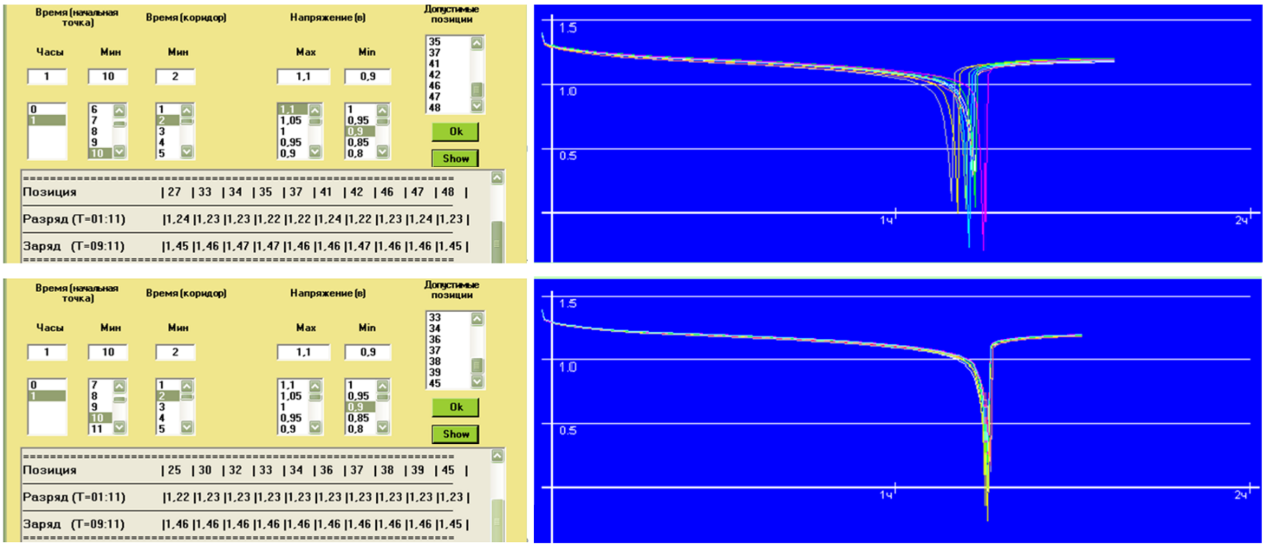

Figure 3 Discharge characteristics of a completed battery with varying degrees of identity of electrical parameters

The exit of manning technology to a qualitatively new level was made possible by creating automated process equipment with software that allows visualization of test results. This made it possible to group cells with similar electrical parameters into batteries so that the battery began to work as a single element. The latter greatly simplifies the battery parameter monitoring system, which is of particular importance, first of all, for lithium systems, as well as for batteries of any other electrochemical systems, for which it is important to ensure high quality and reliable operation.

When equipped batteries operate under conditions varying from cycle to cycle of discharge loads, the voltage values of individual cells do not exceed the permissible values (Fig.4).

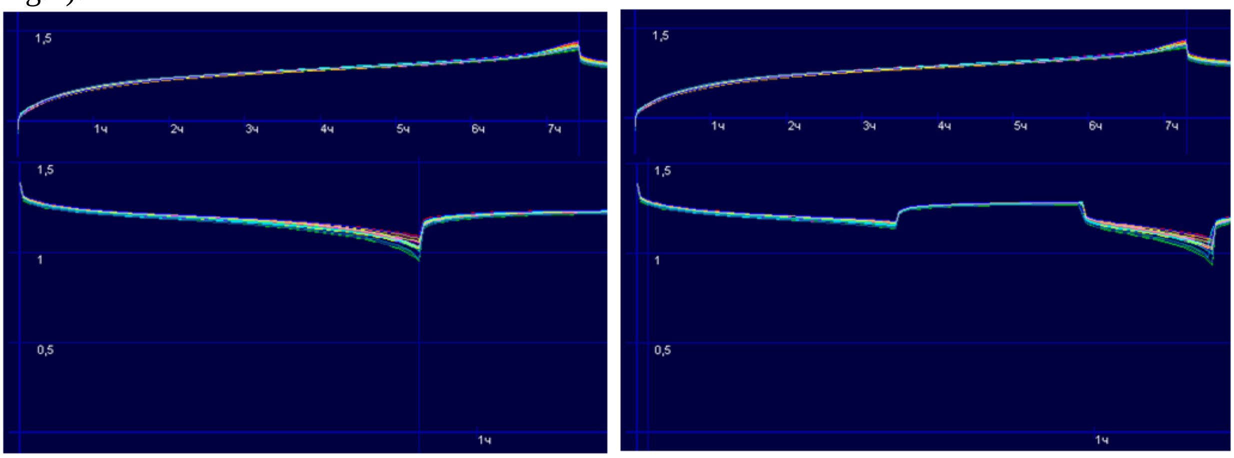

Figure 4 Charging-discharging characteristic of a complete battery

The increase in the imbalance of batteries, consisting of cells with significantly different values of electric capacity during long-term cycling are shown in Figure 5.

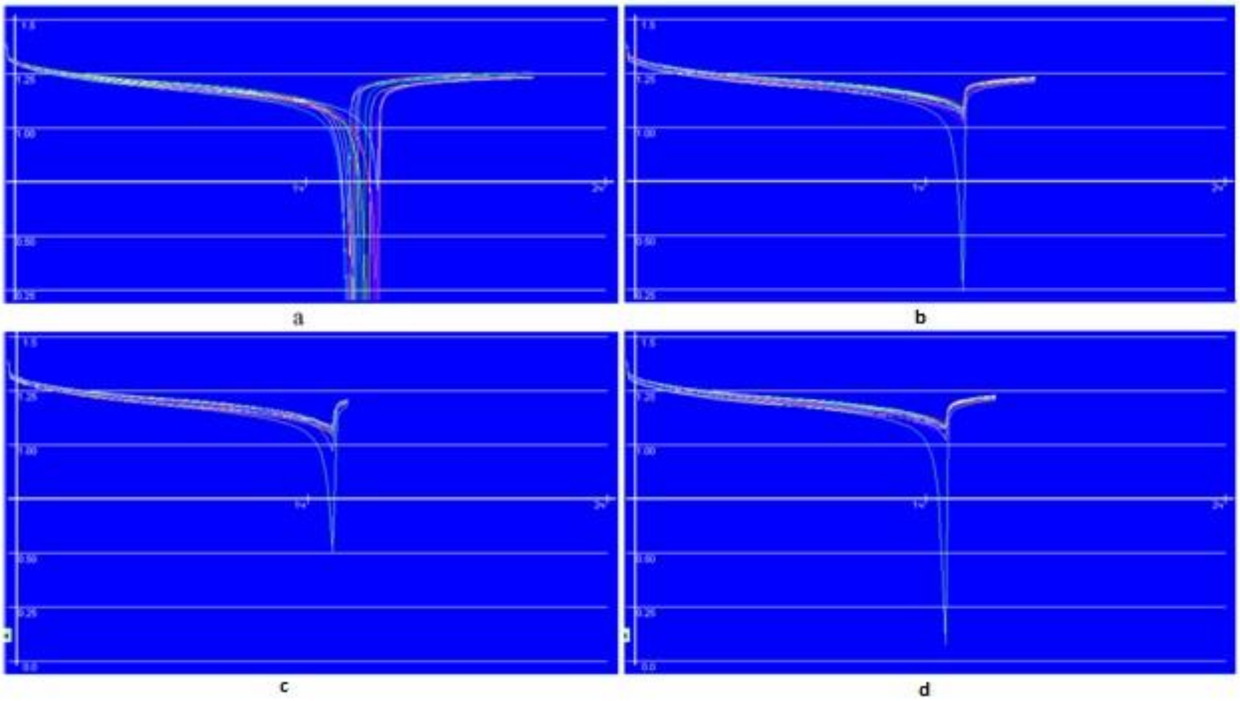

Figure 5 Discharge curves of individual cells - a, and the same batteries as part of a 12V battery - b, c, d during its cycling

The result of the operation of such batteries, consisting of completely sealed cells, as a rule, is the deformation or depressurization of the "weakest" battery body (Fig. 6).

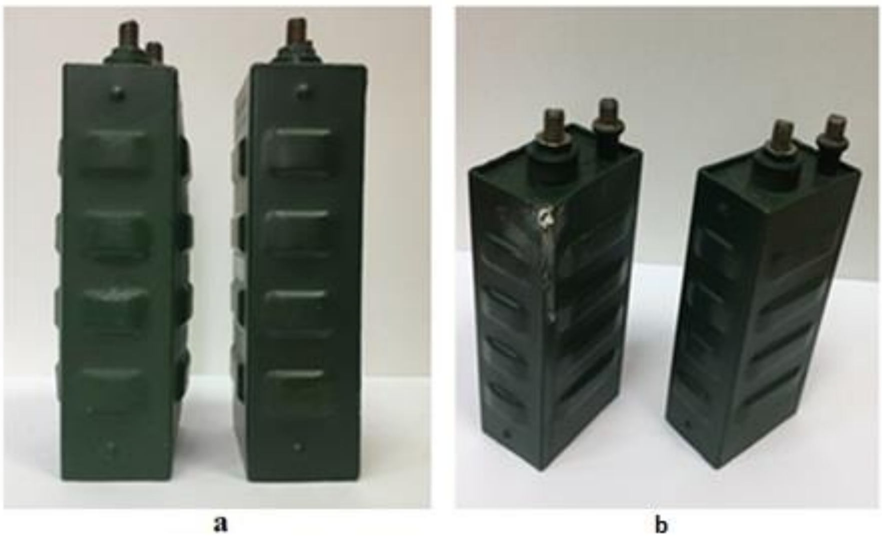

Figure 6 The consequences of the operation of sealed nickel-cadmium batteries in the context of incomplete cells included in them a - deformation of the battery body; b - depressurization..

Recently, in electrical installations based on renewable energy sources, lithium-ion batteries of various modifications are widely used due to the high specific energy consumption and a stable tendency to reduce costs.

Current-forming reactions on the positive and negative electrode are:

$$LiMeO_2 \rightleftarrows Li_{(1-x)}\ MeO_2 + xLi^{+} + xe^{-} \quad (6)$$

$$C_y + xLi^{+} + xe^{-} \rightleftarrows C_yLi_x \quad (7)$$

The use of electrolytes based on organic solvents with a high decomposition voltage in lithium CCR prevents side processes in the operating voltage range of the battery, which ensures their tightness and, accordingly, maintenance-free operation. However, beyond the established voltage range, irreversible chemical processes with the participation of organic substances begin. Therefore, a significant drawback of lithium-ion batteries is the risk of ignition or explosion due to overheating, thermal acceleration due to metastability of chemical compounds, short circuit, overcharging or overdischarge of the battery in real conditions of battery operation. As an example, Fig. 7 shows the discharge data of an incomplete battery (12V, 100Ah) of European-made lithium-iron-phosphate batteries to a monitoring and control device for a long time in conditions of emergency simulation. As it can be seen from the above data, there is a clear imbalance in the voltage values of individual cells in the battery with a going beyond the permissible 2.5 V.

Cells voltage in the battery,V
2,9
3,13
3,19
2,1

Figure 7 lithium-iron-phosphate batteries discharging into the monitoring system for a long time in spare mode

Such violations of operating conditions can significantly accelerate the degradation of individual cells and lead to premature failure of the entire battery. Safe and efficient use of lithium-ion batteries, as well as reducing the effect of battery capacity loss during long-term operation, can be ensured, as is the case with batteries based on aqueous electrolytes, by their proper selection in the battery based on the similarity of electrical parameters. This greatly simplifies the battery monitoring system.

The software of the test benches developed by our scientific and technological center provides for a graphical display of the dynamic characteristics of the batteries, with the possibility of superimposing charts on each other up to 20 cycled cells at the same time, which makes it possible to predict their behavior during operation even at the stage of battery production. The applied testing technique also allows us to identify the following problems during the picking process: micro-short circuits (Fig. 8a), phase changes (second sites on the graphs, Fig. 8b), increased ohmic resistance (Fig. 8c), reduced power characteristics (Fig. 8d) , and taking into account the data obtained, to complete the batteries in the battery with the most similar actual parameters excluding the ingress of potentially unwanted cells into the battery.

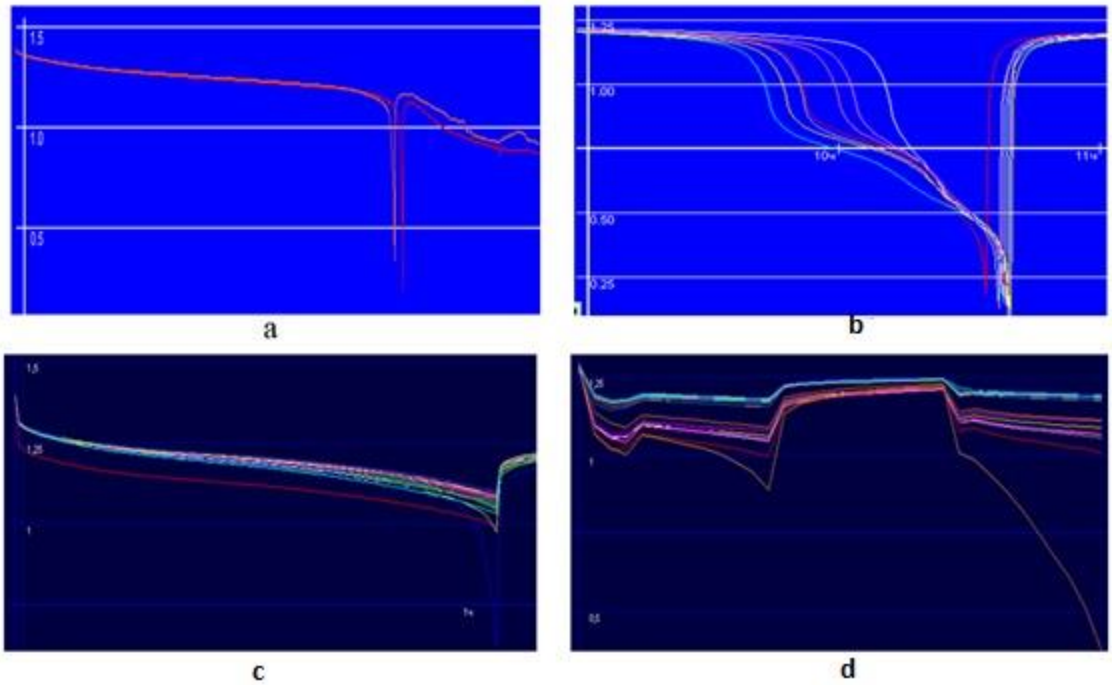

Figure 8 a, b, c, d The effect of battery defects and secondary reactions on its charge-discharge characteristics

Conclusions

1. 1. The choice of drive for autonomous power plants based on renewable energy sources for remote and hard-to-access regions should be carried out taking into account the criteria of maintenance-free, reliability and safety for a long period of operation.
2. The efficiency of the battery of any electrochemical system is determined by the proper completing of the battery, which is achieved by the selection of batteries with close electrical parameters.
3. The creation of batteries that certainly meet the requirements of operation can be achieved using the automated technology for completing batteries, developed by RTC “ANK” LLC.
4. Implementation of the proposed approach to the creation of energy storage devices will allow, with a slight increase in the initial cost of battery production, to significantly reduce the labor costs and financial resources spent during the entire life of power plants..

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