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Automated Measuring Station for Accumulator Testing

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Abstract. The paper describes the design and implementation of the system allowing the testing of the lithium-iron-phosphate ($LiFePO_4$) cell parameters during long-term loading. Manufacturers and retailers, in particular, accentuate their beneficial properties – the possibility of charging and discharging by high currents, minimum influence of the discharge time on capacity, long durability. At the same time, their operational conditions are a lot more strictly defined than those for other types of accumulators. The proposed testing system enables loading the accumulators, consisting of several cells, by periodic discharging and charging processes with various operating currents and various levels of cell discharging. The charging and discharging process control is fully automated; the measuring of the cell operational state is performed automatically during charging and discharging. The data is recorded, and continuously evaluated for the purposes of process management. The measurements enable the comparison of the catalogue data with the parameters of the real products. The testing system design is based on the application of a digital control block, which is completed with an analog control block. The core of the digital control unit is a control computer equipped with a multifunctional input-output card and an array of logically controlled circuit–breakers. An accumulator management algorithm, implemented as a control program of the computer, ensures the operation of the accumulator in subsequent charging and discharging periods. The actual accumulator control is based on the evaluations of voltage levels at the cell terminals.

Key words: $LiFePO_4$ accumulator, testing, Ah capacity, limit parameters.

INTRODUCTION

A lithium-iron-phosphate ($LiFePO_4$) accumulator is nowadays considered to be one of the best types of accumulators with higher capacity (Scrosati et al., 2013; Liberty, 2014). The accumulator belongs to the polymer Li-on accumulators; it was developed at the University of Texas in 1996. It is used whenever high capacity at low weight, volume and longevity are required.

The main advantages of $LiFePO_4$ accumulators are high voltage, low internal resistance and, consequently, very flat volt /coulomb characteristic during discharging and charging. In operational terms, the accumulators are characterized by high lifetime, temperature stability; they do not represent any fire or explosion hazard, even in case of improper handling and they do not contain any toxic metals, acids or alkaloids. They can be charged and discharged by high current; at minimum, by the current corresponding to a one-hour discharge period. Some manufacturers indicate their lifetime up to 2,000 discharge cycles at 100% deep discharge, whereas their capacity is more than 80% of their initial capacity (Scrosati et al., 2013; Liberty, 2014).

$LiFePO_4$ accumulator manufacturers declare their operating conditions and stick to their strict observation. If the accumulators are used improperly, they can be damaged very easily. It can occur; e.g., when the maximum voltage exceeds its limit during charging, or when discharging continues even after reaching a defined minimum voltage, and at the states that may arise due to non-compliant internal parameters of the cells connected in series caused by their ageing (Thunder Sky, 2015a; Thunder Sky, 2015b; Thunder Sky, 2015c; Thunder Sky, 2015d; Sinopoly, 2015; Global, 2015).

Manufacturers and especially distributors indicate that $LiFePO_4$ accumulator operational costs are lower, when compared to other kinds of accumulators, although their acquisition costs are much higher, which is thanks to the fact that they have much longer lifetime.

The aim of the project is to implement an automated measuring workplace for testing cells, which allows setting the operational parameters of the real cells and comparing them with the parameters declared by the manufacturer. The measurements of the parameters are performed by a cyclic discharging of the cells up to the minimal voltage and by their recharging to maximum value. The gradual parameter deterioration after multiple repetitions of the cycles is observed, as well (Cenek, 2003; Lust, 2010).

MATERIALS AND METHODS

The evaluation of operational parameters of specific $LiFePO_4$ cells during the long-term measurement is performed by a special testing system. Charging and discharging processes are controlled by a computer and are fully automated. Operating parameters of the tested accumulator are continuously scanned, recorded and evaluated by the server (Srovnal, 2002; Kreidl & Svarc, 2006).

Individual cells are equipped with balancing and protection circuits that prevent the cell from exceeding the maximum voltage during charging and also from voltage drops below the minimum level during discharging.

The testing system consists of a power supply, electronic load, switch control unit, cell balancers, input-output card and a server, see Fig. 1.

A laboratory power supply MANSON HCS 3402 with a maximum output voltage of 32 V and 20 A current is used as a charger. Selecting both charge current and charge voltage is possible manually, i.e. by setting the source. The source can also be controlled by the computer.

An accumulator discharge is performed by STATRON 3227 Electronic Load. It can operate at a maximum voltage of 80 V, 25 A current and total power dissipation of 200 W. Discharge current is set manually and it is stabilized by electronic load at a preset value. The discharge current stability is better than 1% of the set value, within the range of the discharge voltage at a four-cell $LiFePO_4$ accumulator. Power circuits in the testing system are controlled by relay switches. The relays have a robust construction, and therefore they are extremely reliable. Moreover, polarized bistable relays used in the system do not need permanent operating current. The relays are controlled by logic signals from the input-output card. The signals pass through photocouplers to the transistor switches that control relay coils.

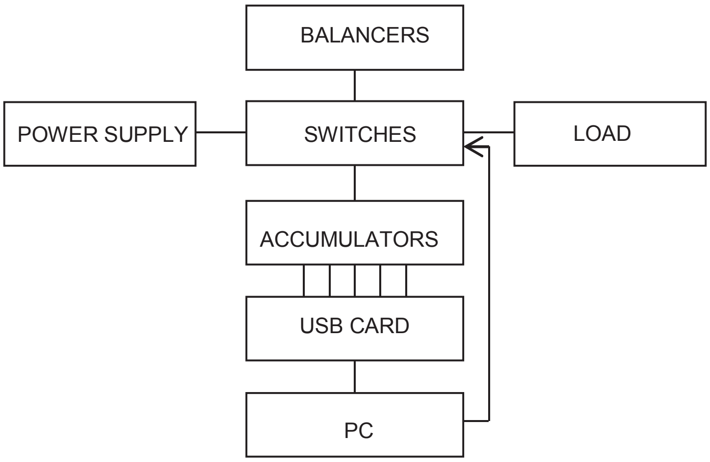

Figure 1. Block diagram of the testing system.

Complying with the desired operating parameters during the charging process is furthermore ensured by a network of analog balancers connected in parallel to each cell. The balancer prevents the cells, which are charged the fastest of all in the charging process, from overcharging. If the applied voltage of the cell reaches the selected value, the balancer consumes charging current supplied from the cell and stabilizes the applied voltage at a selected value. Charging continues until the voltage at all cells reaches the selected value and all cells are not fully charged without exposing any cells to overcharging.

Fig. 2 shows the real voltage courses of two cells at the end of the charging cycle, during the last 5% of the charging time, when the balancing is applied.

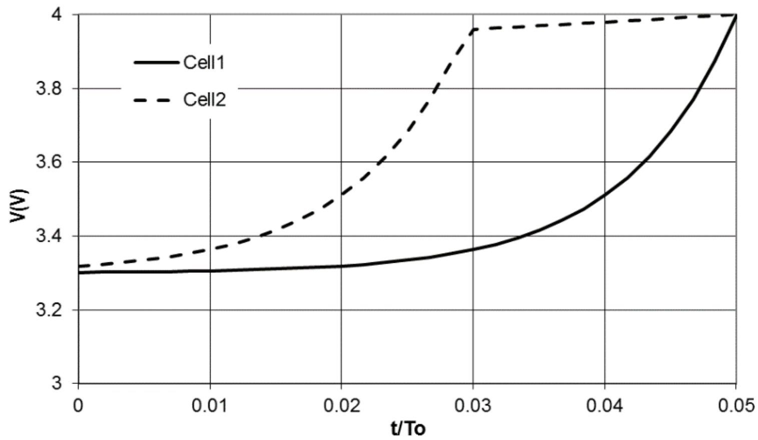

Figure 2. Real voltage waveforms of two cells when applying the balancer.

Herein used balancers are simple analogue circuits autonomous for each cell. A balancer circuit comprises three transistors, a reference diode and five resistors. The balancer also includes two photocoupling ports that can serve for indicating the cell voltage. The balancer I–V characteristic is shown in Fig. 3. When charging at 4.04 V voltage, the current can reach even 12 A, which is higher than the current supplied by the source of the charging current. In an idle-circuit condition, the balancer consumes the current that is less than 5 mA. Such a low current causes only negligible undesirable cell discharge.

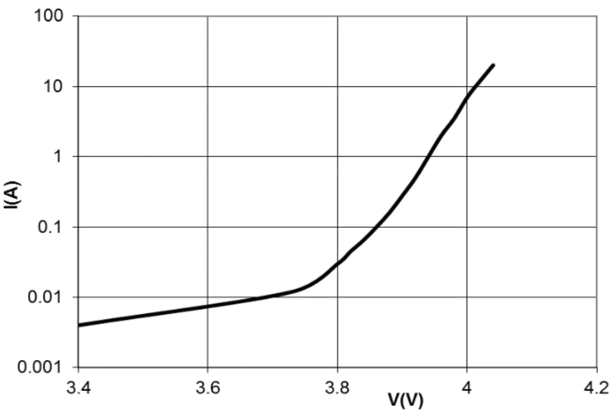

Figure 3. Balancer I–V characteristic.

The testing workplace control is provided by the program in a system-design platform LabVIEW implemented in the PC.

The program structure is based on the workplace block diagram, as shown in Fig. 4.

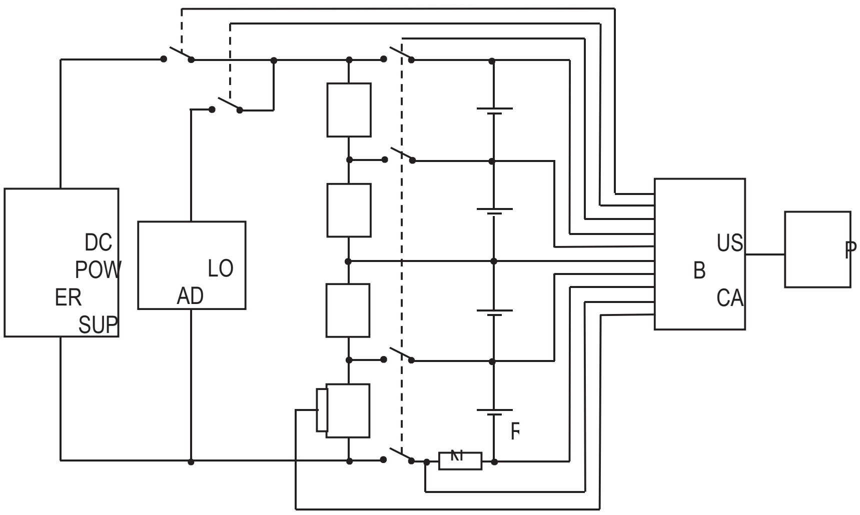

Figure. 4. Block diagram of a testing workplace: B – balancer; SC – charging relay; SD – discharging relay; J – breaker; T – thermometer; RN – ammeter shunt.

The balancers are connected via protective circuits, whose circuit breakers J control the continuous charge and discharge states by means of the program. In this way, the balancers eliminate the state when the accumulators could be severely damaged or completely destroyed. The charging and discharging networks of accumulators are operated by SC and SD switches. At the same time they are controlled by command signals from the LabVIEW program.

During the accumulator charging, the charging source is connected by an SC switch. The diode in the power supply secures the device in case of power failure or malfunction of the charging source. The accumulator discharge occurs by discontacting the SC switch and subsequent contacting the SD switch, which connects STATRON 3227.1 electronic load to the accumulators. The load is manually adjusted to the desired mode, i.e. the discharge by a nominal 10 A current.

Scanning the analogue signals from the accumulators and generating control signals for controlling the function of switches, which set the desired mode and ensure continuous emergency protection of the operating modes, is provided by a measuring card USB 6211. An input card with 16-bit converters enables achieving an absolute error in determining cell voltage of 0.3 mV at a chosen input range of the ± 10 V analogue inputs. Switches SC and SD are controlled by the logic signals of the card.

Control program functions

A control program for the diagnostic workplace is created in a graphically oriented environment LabVIEW on a PC or laptop. Using a laptop is preferable due to its safe circuitry stripping from the mains (Tumova, 2009). The block diagram of the program created in LabVIEW graphical environment is presented in Fig. 5.

In some cases, depending on the accumulator type and manufacturer, the program enables presetting technical parameters of the cells specified by the manufacturer to prevent their overrange limit (Cenek, 2003; Richter, 2014; Global, 2015; Sinopoly, 2015; Thunder Sky, 2015a; Thunder Sky, 2015b; Thunder Sky, 2015c; Thunder Sky, 2015d). Required parameter compliance is provided by a control program which generates a signal, whenever the threshold limit is reached, and consequently, the circuit breakers are switched off. The accumulators are disconnected both from the voltage supply and the load, and thus, they are protected from any further damage.

For the accumulator cells are generally set these parameters:

V_{max_L} – maximum cell voltage at which the voltage protection is disabled;

V_{max_C} – final charge voltage at which the system function is switched to discharging;

V_{min_D} – final discharge voltage at which the function is switched to charging;

V_{min_L} – minimum cell voltage at which the voltage protection is disabled.

The set parameters at Winston Battery cells are presented in Table 1.

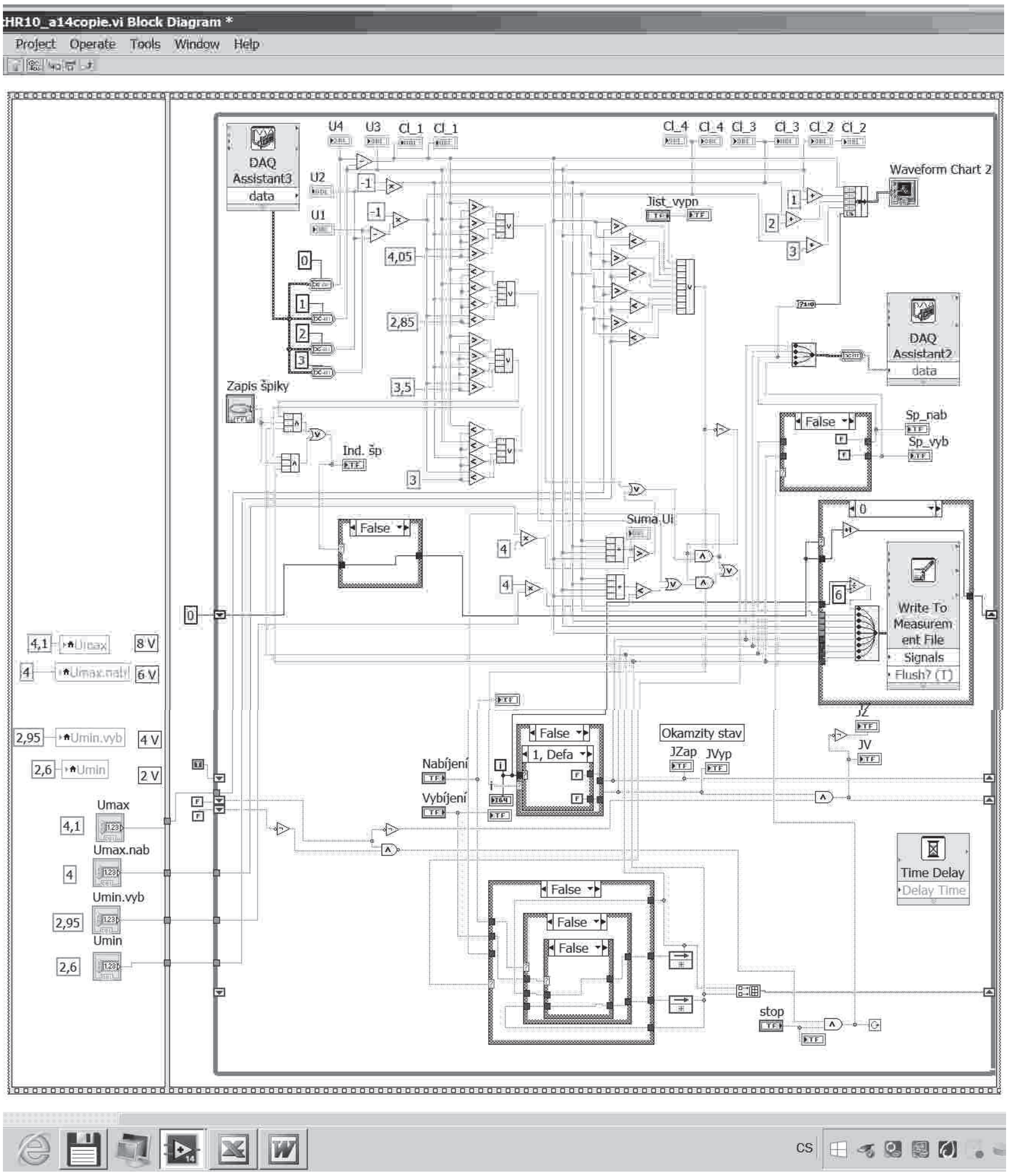

Figure. 5. Block diagram of the LabVIEW control program.

Table 1. The set parameters at Winston Battery cells

V_{max_L} (V)	V_{min_L} (V)	V_{max_C} (V)	V_{min_D} (V)
4.1	2.6	4	2.95

During charging, the maximum charge voltage is primarily controlled by the balancers, whose voltage value is set closely under 4 V. In case this value is reached, the balancer decreases the charge current by consuming its operating current and thus stabilizes the charge voltage.

The cell voltage is further monitored by the control program, and in case the balancer fails to prevent the voltage growth, and subsequent overvoltage V_{max_L}, the control system provides the disconnection of the circuit breakers.

The regular switching the charging and discharging processes is controlled by the control program according to the total battery voltage V_{bat}. If the condition $V_{bat} \geq 4.V_{max\_C}$ is fulfilled, the control program switches automatically from the charge mode to the discharge mode. If the condition $V_{bat} \leq 4.V_{min\_D}$ occurs, the program automatically switches the discharge mode to the charge mode.

One charge/discharge cycle takes about 4 hours at the tested accumulators with nominal capacity of 40 Ah and selected charge/ discharge current of 10 A. Since the voltage at the cells varies during the most of charging and discharging periods very slowly (PowerStream, 2015), for the data record was selected a two-minute interval. Only during a short period of time, taking only a few minutes before the end of the charge/discharge process, in which a rapid change in voltage occurs, it is possible to choose a frequent record, with a 10 s period.

The frequent record is switched off always at the end of the charge/discharge process. The example of the record is presented in Fig. 6.

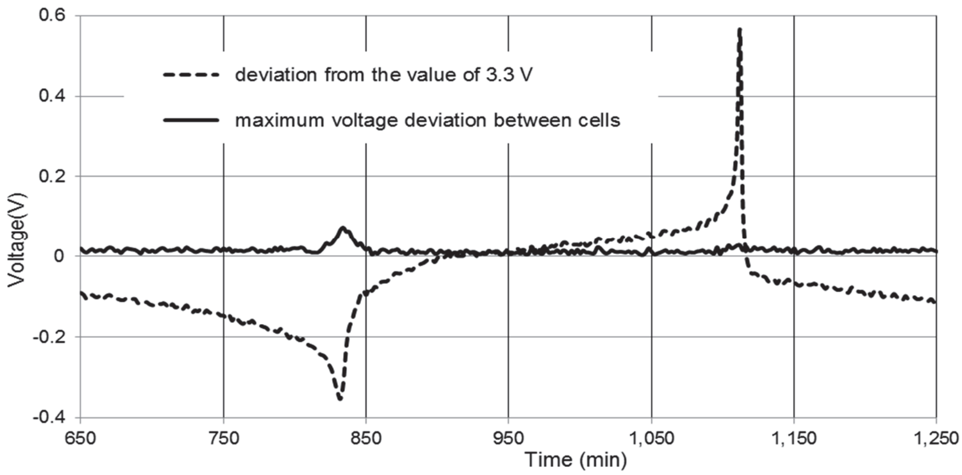

Figure 6. Course of voltage variation at individual 4 cells during the charge cycle.

RESULTS AND DISCUSSION

The measuring system was assembled from commercially available components: laboratory power supply MANSON HCS 3402, electronic load STATRON 3227, measuring card USB 6211, notebook HP Pavilion and other special components, which were developed for this purpose. These are balancers, relay switches and their control circuits.

The operation of the measuring system is controlled by a program implemented in a notebook. The program enables not only continuous recording of the measured values to the file, but also their reading and further displaying in a graphical form. Continuous monitoring of the measured data is also provided by the graphic recording to the Waveform graph placed on a virtual front panel in a LabVIEW program. There are recorded all four cell voltage waveforms (for better clarity always mutually shifted by 1 V), together with a current status of the charge signal (log 1) or discharge signal (log 0). Apart from a continuous display of the measured data and control signals for charging or discharging on the front panel, the data is also recorded directly into the archive file.

The data serves for displaying the charge and discharge waveforms, and if necessary, the data can be subjected to further analysis. The example of the measured data record for a period of 1,424 minutes, which corresponds to three charge and discharge cycles, is shown in Fig. 7.

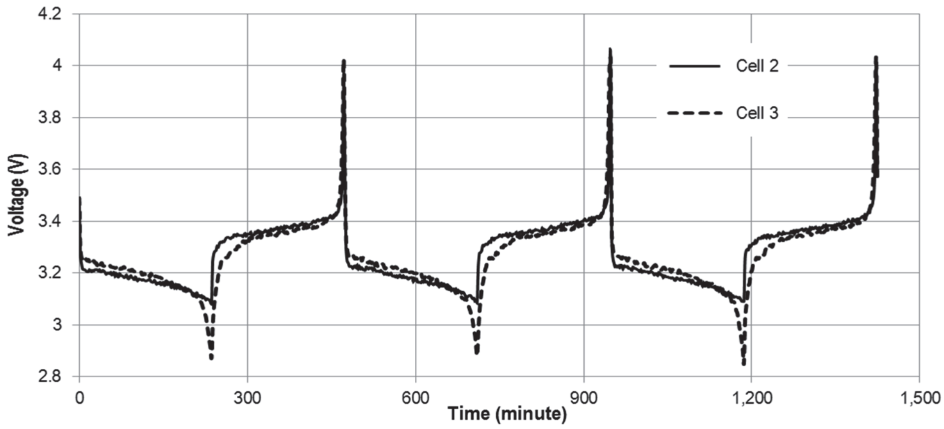

Figure 7. Example of the measured voltage waveforms on the cells within 1,424 minutes.

The measuring workplace in operation is shown in Fig. 8. Fig. 9 presents the view of a computer front panel in operation.

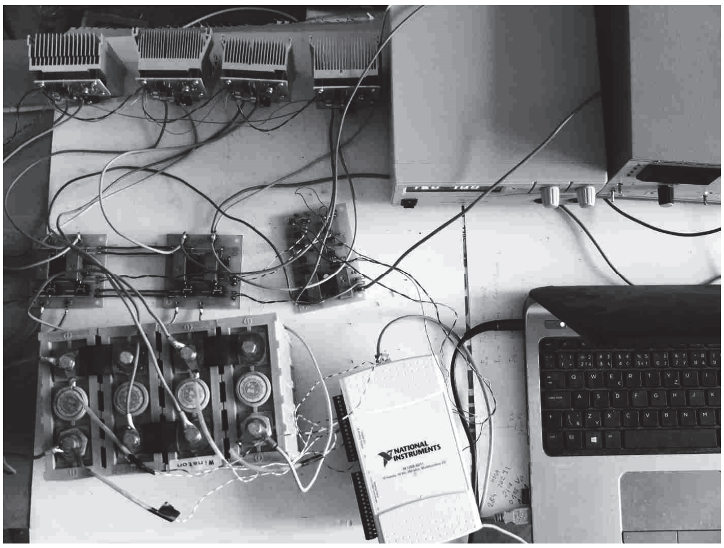

Figure 8. Photo of a measuring workplace.

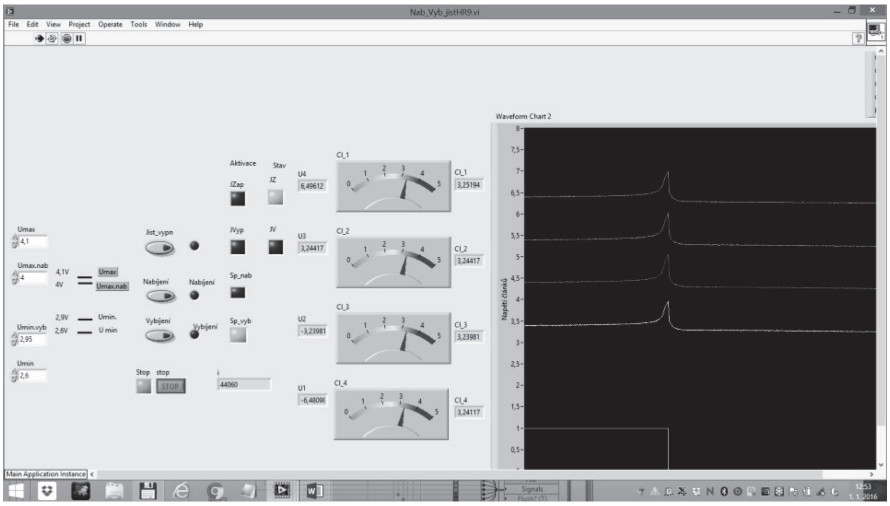

Figure 9. Front panel of the control program in LabVIEW; transition from the charge mode to the discharge mode.

Two equivalent workplaces were realized, one set of batteries was tested on each workplace. The first set was bought in 2013, and before the test started in herein described system, the cells were in operation for about 150 charge and discharge cycles. The second set was bought in 2015 and the cells were applied in the test immediately after initial charging. The results are presented in Table 2. The initial capacity of the cells in the first series was 99% of the nominal capacity; after one hundred cycles with 100% discharge, their capacity decreased to 97% of the nominal capacity. The charge required to charging varied around 102% of the charge consumed during the discharge.

The initial capacity of the cells in the second series was 116% of the nominal capacity; after one hundred cycles with 100% discharge, their capacity decreased to 110% of the nominal capacity. The charge required to charging again varied around 102% of the charge consumed during the discharge.

Table 2. Test results of 4 cells WB-LYP40AHA Winston Battery

	End of discharging voltage (V)	End of charging voltage (V)	Full discharge (Ah)	Full charge (Ah)	Charging efficiency (%)
Set 1 start	12	15.9	39.3	39.6	99.2
Set 1/100 c.	11.92	16	38.6	39	99
Set 2 start	11.84	15.8	46.3	46.6	99.3
Set 2/100 c.	11.84	15.9	44.4	45	98.7

Battery voltage at the end of the charging or discharging is approaching value that corresponds to equivalent at all cells (charging 16 V, discharging 11.8 V) during an operation. This means that the difference between the initially different characteristics of each cell is reduced.

This measurement system is designed for operation with 4 battery cells, it can be reprogrammed to work with fewer battery cells. It is possible to choose the battery charging current within the range of 0.5 A up to 16 A. The battery discharging current can be set within the range of 0.5 A up to 12.5 A. Additionally it is possible to increase maximum discharging current of 16 A by addition of fixed resistor of approximately 0.5 Ω (power dissipation 150 W) into the discharging circuit. The electrical current values are stabilized with an accuracy of ± 1%, the values of cut-off voltages are held with a maximum deviation of 10 mV.

CONCLUSIONS

Measuring workplace described in this paper allows the evaluation of the real accumulator parameters. It enables their potential users to invest their money reasonably, i.e., on the basis of the real verified data and not only on unverified information from producers and traders. At best, they provide positive results of selected tests, whose testing conditions usually do not correspond to the real operation.

A workplace function was verified by more than one hundred cyclic tests on two sets of Winston Batteries. There were verified voltage waveforms of both sets during charge and discharge by a constant current in the range of voltage levels recommended by the manufacturer. Their ampere-hour capacity and charging efficiency was also determined.

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