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Multipurpose Rechargeable Battery Module

Tsykhmystro A.S.[1], Kuzmichev I.K.[2]
[1]*Limited Liability Company "The Best Element",*
[2]*The A.Ya. Usikov's Institute for Radio Physics and Electronics of the NAS of Ukraine,*
Corresponding Author: Kuzmichev I.K.

ABSTRACT: *The rechargeable battery module of 2 kW·h capacity containing 152 cylindrical 18650 Samsung cells is proposed in the paper. The study has shown that the cells cooling system used in the module can significantly reduce the cells charging time. It was found that the temperature of cells does not exceed +28.4°C when the module is charged with high currents (295 A). The module's unique fire extinguishing system makes it absolutely safe for use in electric vehicles and other devices.*
KEYWORDS: Electric Car, *Rechargeable Battery Module*, Module Charging; *Module Discharging;* Cooling System; Fire *Extinguishing* System.

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I. INTRODUCTION

The most important reason limiting mass appearance of electric cars is not their high cost, but the time of the battery charging. Nowadays it is possible to distinguish several methods of the battery charging [1]. The first method is the base one. In this case, the battery is charged by an AC household supply line. The cord without the additional safety devices is plugged into a common outlet socket. The charging time of a standard electric car with a battery of 20÷25 kW·h is about 6-8 hours. The second method differs from the first one by the use of an original cord with protection. Depending on the type of a cord (single-phase or three-phase), the charging station power is from 7.2 to 43 kW. Due to this, the charging time of a modern electric car can be reduced to 1 hour. At present the fastest method is the charging an electric vehicle using DC. The charging stations of Tesla Supercharger make it possible to use 120 kW power current, while usual stations provide only 10 kW [2]. The network of the charging stations Megacharger (analog of Supercharger for Tesla cars), will be set up for the trucks and will provide a battery charging up to 80% (sufficient for almost 650 km) in 30 minutes [3]. At the fast charging, the problem of a battery overheating arises. A battery life is shortened at high temperature of the cells during its charging. To avoid this, the charger should control the state of the battery each millisecond and follow its basic parameters such as voltage and temperature since the battery is most expensive part of an electric vehicle.

Nowadays there are no better batteries than lithium-ion ones in terms of energy density and mass/size ratio in a mass production. Using Panasonic 18650 lithium-ion cells, Tesla Motors has created a balanced battery with a capacity of 100 kW·h, providing all-electric range of ~ 500 km [4]. One of the recently trends is the search for more powerful sources of energy. So the company Tesla Motors launched the production of lithium-ion cells of the new form factor 21700 [5]. It is also worth noting that the long life of the battery of the electric car Tesla Model S is achieved due to the improved design of cells with the maximum output voltage 4.35 V and reduced internal resistance. In this case, we assume that the cooling system proposed by Tesla Motors [6] is not optimal.

Together with a number of advantages, lithium-ion batteries possess several drawbacks: the possibility of an explosion during the charging or mechanical damage of the battery, which can cause a fire of a car in the case of the traffic accident and quite high cost of batteries [7].

These features of the operation of lithium-ion batteries take place at a temperature of ambient air from + 5°C to + 45°C [8]. However, there is the question what happens to the process of the battery charging at the negative air temperature? Some authors [9] assert that lithium-ion batteries cannot be charged outdoors, in the garage and other places at negative air temperature. Rapid charging at this temperature is totally unacceptable since it results in the metallic lithium particles hit an anode. This coating does not vanish during charging and discharging cycles. Cells with such coating become less fault-tolerant and can fail, for example, under vibration [10]. In addition, such a solid coating of the anode with lithium, as a rule, causes irreversible loss of capacity of the cells. Thus, at a low temperature of ambient air, the battery should be charged with a low current. Thus, at a temperature of -30°C, the permissible charging current should be 0.02C (C is the battery capacity) [10].

Therefore, the modern electric car batteries are equipped with complicated temperature controllers. Such controllers cool the battery under an increased load [6] or contrariwise heat it when connected to a charging station at low air temperatures. The performance of such a system mainly depends on the design of the battery module. Tesla Motors has proposed a solution to this problem [11]. However, Tesla Motors' temperature controlling system is not perfect. Thus, the purpose of this work is to create and study a battery module based on 18650 lithium-ion cells with effective temperature controlling and fire extinguishing systems.

II. DESCRIPTION OF THE BATTERY MODULE

We took the battery of the company Tesla Motors as a basis since it is one of the best in the world. Since it is almost impossible to assemble a similar battery without special equipment, we have created a separate battery module. Its block diagram, as a composite element of the battery, is shown in Fig. 1, and its appearance is shown in Fig. 2. This battery module contains Samsung INR18650-35E cylindrical cells.

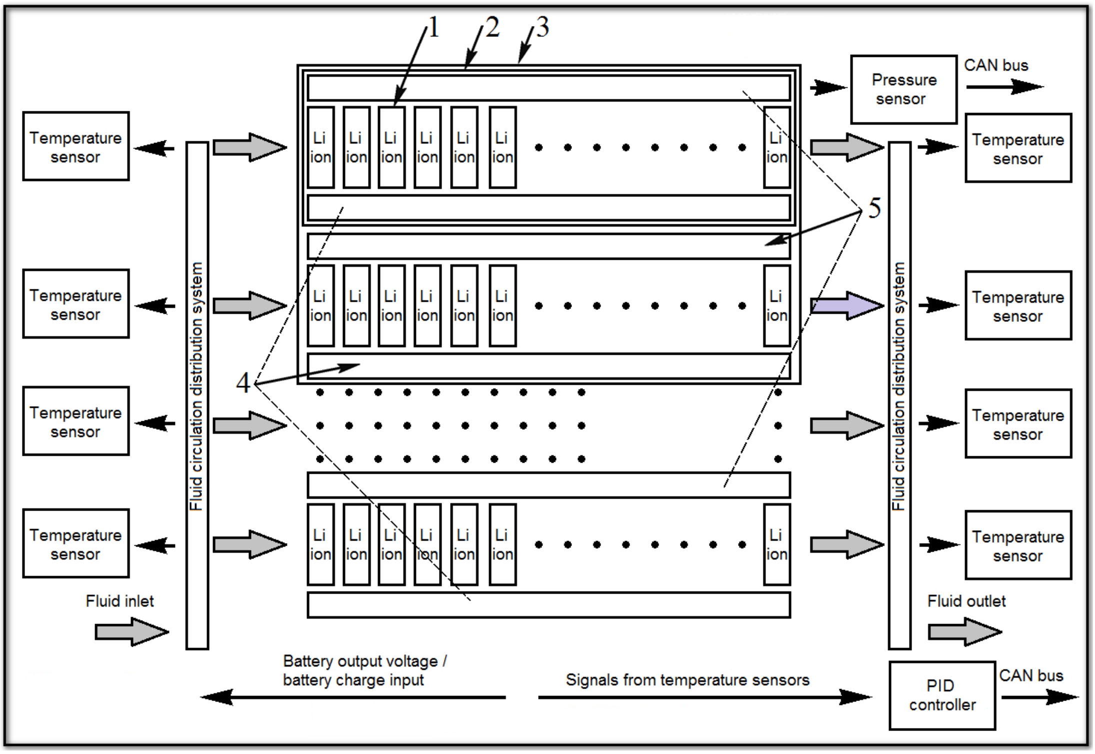

Fig. 1. The block diagram of the battery

Here 1 is the lithium-ion cell Samsung INR18650-35E; 2 is the battery module; 3 is the battery assembly that includes several modules; 4 is cooling (at high air temperatures) or heating (at negative air temperatures) system; 5 is the fire extinguishing system.

In the fig. 2, the numbers indicate: 1 - inlet of inert gas; 2 - inlet of the fire extinguishing powder; 3 - power cable connection (+); 4 – power cable connection (-); 5 – inlet of the cooling (heating) fluid into the module; 6 – outlet of the cooling (heating) fluid from the module; 7 – input of all communications to the module; 8 - safety valve.

The considered battery module contains 152 cells, which are connected as eight arms in series; each arm contains 19 cells connected in parallel. This ensures very reliable operation. Even if several cells fail, the module remains in a normal operation. The balancing current necessary for a small correction during the operation of the module is equal to 250 mA.

The module's capacity is 2 kW·h. It consists of one sealed unit with following parameters: 33.6 V (8×4.2 V), 57 A. The dimensions of the module are 310×270×100 mm. Its weight is 15 kg. At industrial production, the weight of the module will not exceed 10 kg. It contains two cooling (heating) circuits, which cover all module elements on their outer surface [12]. Its block diagram is shown in fig. 3.

Fig. 2. Photo of the investigated battery module

The small loop in the figure is indicated by the number 6, whereas the large one is indicated by number 7. The battery module 11 is connected to the charging station 10. After the voltage on the module and maximal charging current is read, the liquid pump 12 is on to circulate the liquid in the cooling (heating) system along the small loop 6 (see Fig. 3) through a three-way valve 14 (inlet 1, outlet 2). This circuit includes the battery module 11; heater 13; liquid pump 12. Thus, the temperature of all cells 1 (Fig. 1) of the module 11 is equalized.

In the process of charging by high current, the battery cells 1 are heated and, as a result, the temperature of the liquid in the cooling system rises up to +45°C. At this moment, the switching from a small 6 to a large 7 loop occurs by means of a three-way valve 14. Large loop 7 includes: battery module 11; three-way valve 14 (inlet 1, outlet 3); chiller 17; external radiator with a fan 15 (in the car it is a structural element); three-way valve 16 (inlet 3, outlet 2) liquid pump 12 or three-way valve 16 (inlet 1, outlet 2) and additional structural elements of the module which includes conditioner compressor 19, radiator with a fan 18 connected in accordance with Fig. 3. The fan 15 is turned on and off by a command from the controller 8 to stabilize the temperature of the cooling (heating) liquid. The controller 8 reads information from the microcontrollers of the monitoring and control BMS systems through a proportional-integral-differentiating (PID) controller 9. In its turn, the microcontrollers read information from digital temperature sensors that are installed inside the battery module 11. Note that the optimum temperature inside the module to start the charging process ranges from +5°C to +45°C.

The chiller can both cool and heat the flowing liquid. If the ambient temperature changes from -5°C to +5°C, the battery module heating should be carried out by the conditioner compressor 19. In this mode, the large loop 7 (the so-called alternative large loop) is on and it includes module 11; three-way valve 14 (outlets 2, 3); chiller 17; radiator with a fan 18; three-way valve 16 (inlet 1, outlet 2); liquid pump 12. Here the chiller 17 is heated up that result in the thermal control fluid heating. This is due to the fact that the conditioner compressor 19 consumes significantly less energy than the electric heating element 13.

During the summer period, the battery temperature is maintained in the range from +25°C to +45°C. The abstraction of a large amount of heat from the cells 1 (Fig. 1) during charging by high currents takes place by means of a liquid flowing through the large circuit 7. It includes: module 11; three-way valve 14 (inlet 1, outlet 3); chiller 17; conditioner of compressor 19; radiator with a fan 18; radiator with a fan 15; three-way valve 16 (inlet 3, outlet 2), liquid pump 12.

A chiller is a plate heat exchanger in which liquid flows on one side and freon flows on the other. It comprises a system that cools the liquid circulating in the battery module and heats the freon, which is the compressor of the conditioner 19. The heated freon enters an external radiator with a fan 18 where it is cooled.

Thus, we succeeded to create a power supply with a temperature stabilization. The uniform flow of liquid in the module is provided by the proper diameters of corresponding channels of the thermal control system. This eliminates the possibility of overheating or overcooling of any cell 18650.

The proposed innovative system of thermal stabilization allows reducing the module charging time. Battery cells do not lose their basic properties when charged with high currents (295 A). At the summer period, the module will not overheat during charging and operation, and at the winter period, energy recovery will start from the moment of a car running without loss of the battery capacity.

In addition to the fundamentally new thermal stabilization system, the battery module contains a unique fire extinguishing system [12]. As can be concluded from available sources, none of the batteries in use today has a similar system.

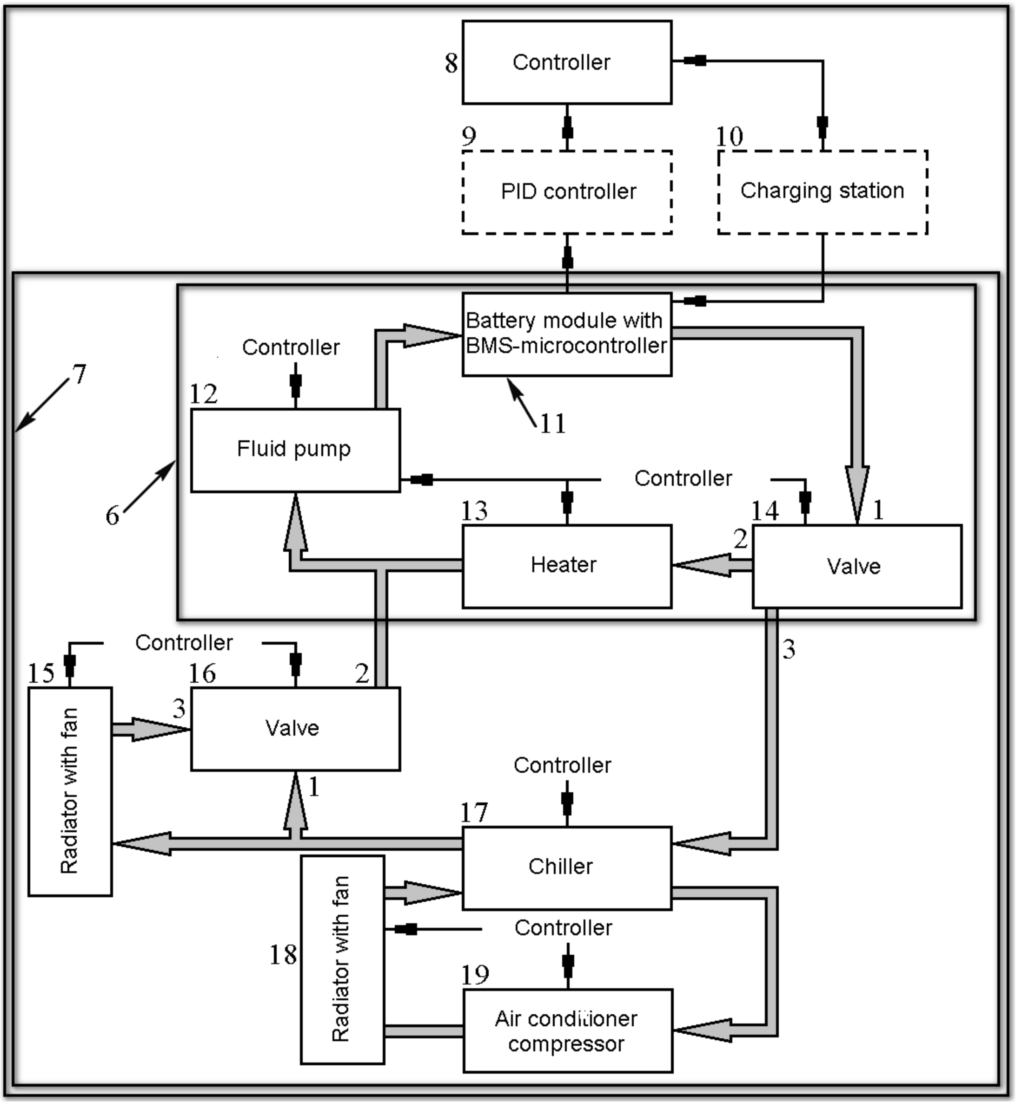

Fig. 3. The cooling (heating) system of the battery module

The fire extinguishing system of the module consists of two levels. The first level performs two functions. The first one is the creation of an oxygen-free environment in the module with cells 18650. And the second one is the suppression of electrolyte emissions into the module chamber in the case of the overheating of cells. The oxygen-free environment in the module provides a complete shutdown of the oxidative processes inside the cells 18650. At the same time, the maximal permissible intra-modular pressure is created, which differs from the atmospheric one. Due to this, in the case of a module damage, there will be the instantaneous release of inert gas from its chamber and further expulsion. This prevents fire in the initial stage and the possibility of an explosion. The verification of the proposed fire extinguishing system is the subject of further research by the authors.

III. EXPERIMENTAL RESEARCH

The analysis of the battery module charging at various ambient temperatures was carried out with the use of the climatic chamber. The block diagram of the experimental setup is shown in Fig. 4. Fig. 5 shows the appearance of the climatic chamber.

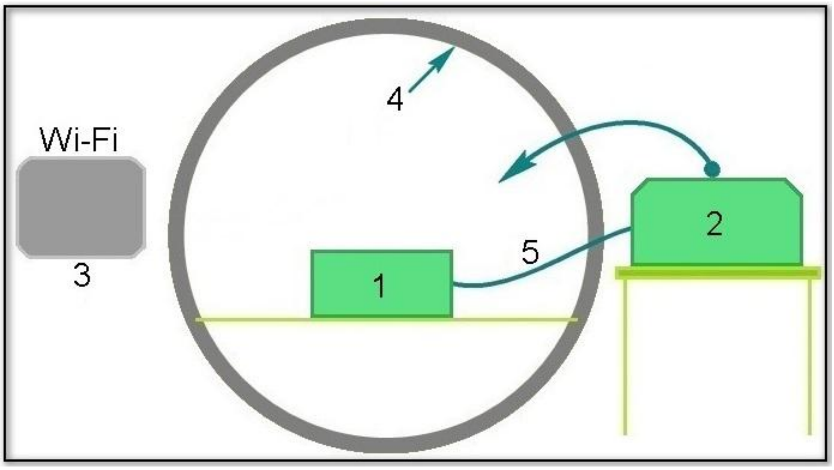

Fig. 4. The block diagram of the experimental setup

Here 1 is the investigated battery module; 2 is the control unit, which includes the elements shown in Fig. 3; 3 is the tablet PC, data to which is transmitted from the control unit using wireless Wi-Fi; 4 is the climatic camera; 5 are communications connecting the battery module with the control unit.

At the first stage, the studied battery module was maintained for 24 hours indoors with a climatic chamber, the temperature of which was +24°C. This was done to equalize temperatures in the module and indoors. After that, the battery module was discharged on a load resistance of 0.85 Ohms. The time dependences of the voltage on the module and the discharge current are shown in Fig. 6.

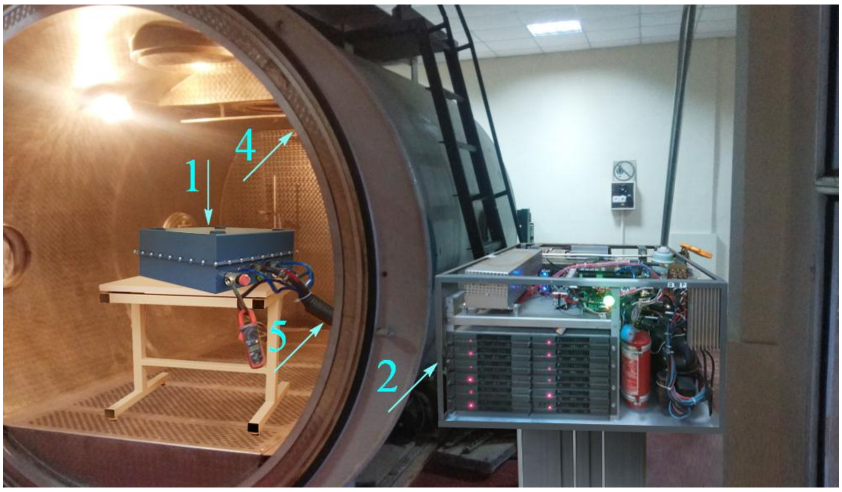

Fig. 5. The appearance of the climate chamber

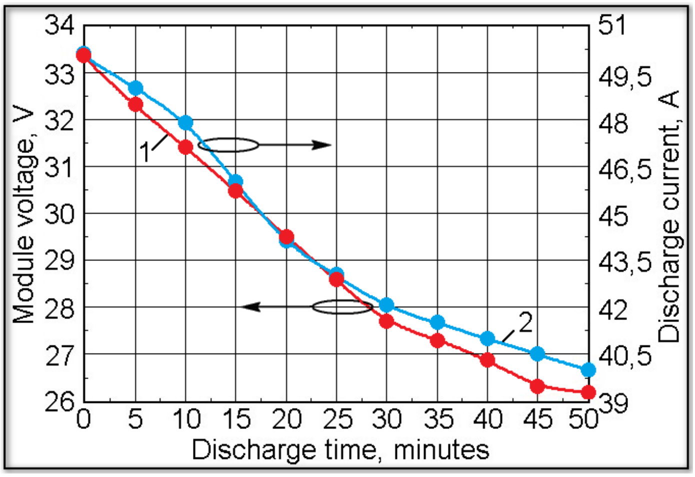

Fig. 6. Dependences of voltage and current on time during the discharging of the battery module

At the moment the discharging started, the voltage on the module was 33.32 V (curve 1), and the discharging current was 50 A (curve 2). After 50 minutes, the voltage on the module dropped down to 26.2 V, and the discharging current decreased down to 40 A. After that, at the ambient temperature of +24°C, the module was charged with high current, which initially was 295 A (Fig. 7, curve 2). Every three minutes during the module charging, the temperature of cells was monitored.

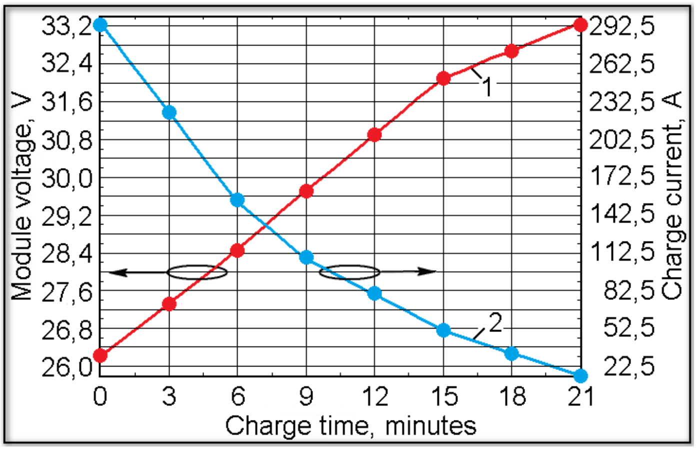

Fig. 7. Dependences of voltage and current on time in the process of charging a battery module at the ambient temperature of +24°C

The figure shows that the module is charged in 12.5 minutes (curve 1) up to 80% (31.12 V) of the maximum voltage (33.6 V), and in 21 minutes is charged up to 94.6% (33.2 V). At this moment, the charging current was 15 A.

At the next step, we checked the battery module behavior with the proposed cooling (heating) system when it is charged with high currents at low temperatures. For this, the module was placed in a climatic chamber, in which the temperature was lowered to -30°C. At this temperature, the module was kept for several hours and then was discharged at the same load resistance down to 26.2 V. After that, the module was charged with high current (295 A) at the indicated temperature in the climate chamber. As in the previous case, every three minutes using a tablet PC (see Fig. 3), the temperature on the cells of the module was monitored. In this case, the dependences of voltage and current on the module charging time are similar to those shown in Fig. 7.

It is of practical interest to study the battery module behavior at high temperatures. For this, we have set the indoors temperature (+24°C) in the climate chamber. The battery module was kept at this temperature to equalize the temperature in it and indoors. After that, the temperature in the climate chamber was raised up to +65°C. At this temperature, the module was again kept for several hours to equalize the temperatures. Then we discharged the module on the same load resistance down to a voltage of 26.2 V. At the next step, the battery module was charged when the temperature in the climate chamber was +65°C. During the charging, the temperature on the module cells was monitored every three minutes. The behavior of the voltage on the module and the charge current, in this case, is similar to the curves shown in Fig. 7.

Fig. 8 shows the temperature on the battery module cells versus the charging time at different ambient temperatures (curve 1 - ambient temperature +24°C, curve 2 - -30°C, curve 3 - +65°C).

As can be seen from the above figure, the cells temperature rises at the high current charging for all three values of the ambient temperature. At the first stage of the charging shorter than ~10 minutes at an air temperature range between +24°C and + 65°C (Fig. 8) (curves 1 and 3, respectively), a small cooling circuit 6 is used to cool the cells (Fig. 3).

At the temperature +65°C in the climatic chamber, the temperature on the module cells grows much faster (curve 3) than it does at +24°C (curve 1). At the moment of the switching the large cooling circuit 7 on (Fig. 3), the temperature does not exceed +28.4°C, that corresponds to a charging time of 9 minutes. During the further module charging at a high temperature in the climate chamber, the cells temperature remains constant and approximately equals to + 26.8°C (curve 3).

At the ambient temperature of +24°C, the heating of the cells is slower and reaches temperature of +28.4°C with a charging time equal to 12 minutes. At this moment, the large cooling circuit is switched on, and the cells temperature during the further module charging is almost unchanged (curve 1).

At an air temperature in the climate chamber equal to -30°C (curve 2), the air temperature in the module, due to its special design, remains positive. The same small circuit 6 is used to cool the module cells when charging with high current (295 A at the moment the charging starts). In this case, the heating of the cells is much slower.

The temperature on the module cells reaches 26.1° C at the moment when charging time is equal to 12 minutes. The charging current here remains quite high and amounts ~80 A (Fig. 7). Therefore, the large circuit 7 is switched on to stabilize the temperature of the battery module cells (Fig. 3). This is clearly seen in Fig. 8 (curve 2): as the module charging further proceeds, the cells temperature is almost without change.

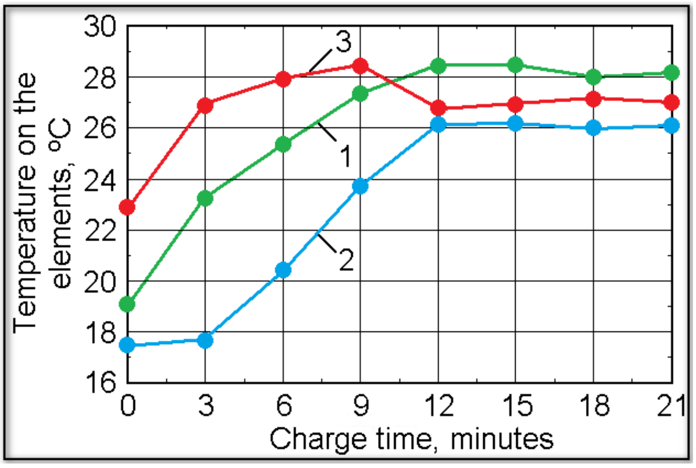

Fig. 8. Dependences of the module cells temperature on the time when charging by high current at various temperatures in the chamber

Thus, experimental studies have shown that the proposed system of cells cooling (heating) will allow effective use of rechargeable batteries assembled on the basis of separate modules in electric vehicles, electric motor yachts, as power banks.

IV. CONCLUSION

The studies of the battery module with a fundamentally new cooling (heating) system allow drawing several important practical conclusions.

1. The proposed cooling (heating) system of cells significantly reduces the charging time of the module due to high currents (295 A). In the process of charging, the temperature on the module cells does not exceed +28.4°C at the ambient temperature of +65°C.
2. Experimental studies have showed that the module cells do not lose their basic electrical properties at high (+65°C) and low (-30°C) ambient temperatures and when charged with high currents (295 A).
3. The battery, consisting of modules similar to the considered one, outperforms the Tesla Motors battery, which is one of the best in the world nowadays.

REFERENCES

[1]. "How to charge an electric car" / Online magazine "Electrocars" [electronic resource] // https://electrocars.ua/how-to-charge/ (in Russian).

[2]. Skripin V. "Tesla plans to charge electric vehicles in just 5 minutes" / Online magazine "Hi-News.ru" [electronic resource] // https://hi-news.ru/auto/tesla-planiruet-zaryazhat-elektromobili-vsego-za-5-minut.html (in Russian).

[3]. Chernonozhkina O. "Tesla Semi – the brain did not blow up" / Online magazine "Capital" [electronic resource] // https://kapital.kz/lifestyle/65145/tesla-semi-mozg-ne-vzorval.html (in Russian).

[4]. "Tesla Model S — technical characteristics and features" / Online magazine "Tesla. Electric vehicles Tesla. The future is already here" [electronic resource] // http://autotesla.ru/auto-tesla/model-s/tesla-model-s-texnicheskie-xarakteristiki-i-osobennosti.html (in Russian).

[5]. Ortega I. "Tesla launched production of the latest type of lithium batteries on "Gigafabrika-1" / Online magazine "Life.ru" [electronic resource] // https://life.ru/p/956048 (in Russian).

[6]. Patent application title: FAST CHARGING WITH NEGATIVE RAMPED CURRENT PROFILE Inventors: Vineet H. Mehta (Mountain View, CA, US) Jeffrey B. Straubel (Menlo Park, CA, US) Assignees: TESLA MOTORS, INC. IPC8 Class: AH02J700FI USPC Class: 320160 Class name: Electricity: battery or capacitor charging or discharging battery or element charging multi-rate charging (e.g., plural charge rates before a maintenance charge, etc.) Publication date: 2011-06-30 Patent application number: 20110156661.

[7]. "Market overview of batteries for electric vehicles" / Online magazine "Engine of Progress" [electronic resource] // http://www.oprogresse.ru/index0a13.php (in Russian).

[8]. [8] Tul D. "Permissible temperature ranges for charging and discharging lithium-ion batteries" / Online magazine "Mugen Power Batteries" [electronic resource] // https://habrahabr.ru/company/mugenpower/blog/171845/ (in Russian).

[9]. "Effect of frost on Li-Ion batteries" // Online magazine "Voltbikes" [electronic resource] // https://www.voltbikes.ru/blog/electro/vlijanie-moroza-na-li-ion-akkumuljatory/.

[10]. "BU-410: Charging at High and Low Temperatures" /Online magazine "Battery university" [electronic resource] // http://batteryuniversity.com/learn/article/charging_at_high_and_low_temperatures.

[11]. Patent application title: LOW TEMPERATURE FAST CHARGE Inventors: Kurt R. Kelty (Palo Alto, CA, US) Clay H. Kishiyama (San Mateo, CA, US) Sarah G. Stewart (San Francisco, CA, US) Sarah G. Stewart (San Francisco, CA, US) IPC8 Class: AB60L1118FI USPC Class: 320109 Class name: Electricity: battery or capacitor charging or discharging element or battery charger structure charging station for electrically powered vehicle Publication date: 2015-03-19 Patent application number: 20150077057.

[12]. Patent application title: ACCUMULATOR BATTERY. Invertors: Alexander S. Tsykhmistro (Ukraine), Igor K. Kuzmichev (Ukraine). Class: H01M. Class name: Methods and devices, such as batteries, for the direct conversion of chemical energy into electrical energy. Class: H02H. Class name: Protection schemes for electric lines, machines and devices. Publication date: 2019-12-10. Patent application number: 120490 (in Ukrainian).

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