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Modeling of the thermal regime of a mobile electric vehicle charge unit

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Abstract. Rechargeable batteries are an important element in mobile electric vehicle charging systems. Batteries have an operating temperature range, and outside of this range the performance will be reduced or the equipment will cease to function. It is problematic to check this situation experimentally due to the number of batteries used (1200 pieces), so it is necessary to simulate the thermal operating conditions beforehand. The simulation has been performed in Comsol and a preliminary confirmation of the operability of the batteries in the mobile electric vehicle charging unit has been obtained.

1 Introduction

While the adoption of electric vehicles is accelerating at an unprecedented rate, the lack of charging infrastructure hampers the development of this market. To compensate for these shortcomings, mobile charging stations capable of providing charging services without restrictions on the location and timing of the charging process could play a prominent role in accelerating the penetration of electric vehicles [1, 2].

An important step is to simulate the thermal behaviour of the battery in the installation to validate the performance.

Numerous studies are being carried out to develop safe and durable batteries with higher capacity and specific energy [3, 4]. The evolution of energy storage systems has led to the development of lithium ion batteries. Currently, lithium-ion batteries have become the dominant technology, especially in the electric vehicle market due to their high specific energy and power, long life cycle and lack of memory effect [5]. Typically, lithium-ion batteries are connected in series and/or in parallel to create an energy storage system with the desired voltage and capacity. During operation, the assembly of many cells in one compartment causes an increase in temperature, leading to localised wear and tear or even explosion if not addressed [6, 7]. Li-ion batteries have an optimal operating temperature range from 0 to 35 ° C for safe use [8, 9]. Consequently, an air conditioning system is required to dissipate excess heat and to ensure an even temperature distribution inside the mobile electric vehicle charging unit (MECU). Lithium-ion batteries are sensitive to high and low temperatures. Thus, thermal management is necessary to keep the cell temperature

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of the energy storage system within the optimum operating range and to ensure safe and efficient use [10].

Temperature management of batteries is important because of the high energy content and the risk of rapid temperature increase in the high current range [1]. The reliable and safe operation of these batteries is seriously threatened by temperatures outside the operating temperature range. It is necessary to have a simple but accurate model to evaluate the thermal behaviour of the accumulators under different operating conditions and to be able to predict the internal temperature of the container. To achieve this objective, a model is developed to investigate the evolution of the temperature distribution in lithium-iron-phosphate cells. It is assumed that the heat release inside the battery is uniform [12,13]. The heat transfer from the battery surfaces to the environment is nonuniform, i.e. it depends on the temperature of a particular point on the cell surface. In addition, the model is adapted for implementation in battery control systems. This model can be used to scale up batteries and large battery packs. Successful battery pack design starts with the correct selection of the thermal properties of the battery. The use of high temperature resistant materials, such as binders in electrodes and polymer separators, is inevitable in high performance battery design, but this limits the heat transfer within the cells [14]. However, temperatures outside the operating range are not allowed for safety and reliability reasons; they can accelerate battery degradation and even lead to thermal failure [15]. Such a system requires an efficient thermal model with a limited number of parameters measured in each state.

In this study, LiFePO4 LF280K high capacity 280A·h batteries are used.

According to GOST 15150-692 for Cold Temperatures 1, operating temperature is -60° to +40° and LF280K operating temperature is 0-35°, therefore let us formulate thermal calculation tasks:
- to simulate a single module of 4 batteries in order to obtain a graph of the temperature variation of the batteries during the charging process. The result will be a model of the module that can be scaled for thermal calculation of the whole unit;
- simulate the block to get a graph of the temperature change during the battery charging process and the average air temperature in the block. As a result, select the thickness of the insulation, confirm the pre-selected heater output and the temperature to be maintained for cooling.

1.1 Simulation of a single module consisting of 4 rechargeable batteries in order to obtain a graph of the battery temperature variation during the charging process

In order to perform thermal analysis, a 3D geometric model of the module is created in the COMSOL software package, shown in Figure 1.

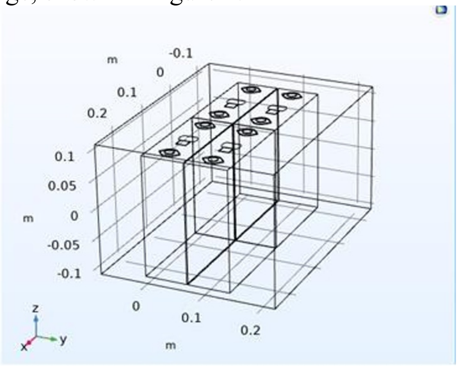

Fig. 1. Geometric model representation of an object

A physical model is created in the COMSOL software package to perform the thermal analysis. The creation of the physical model begins by filling the geometric model with materials that have properties that reflect thermal characteristics.

The basic materials for the thermal analysis are selected as ready-made parameter sets from the COMSOL library: Air, Active Battery Material. Next, in order to perform the simulation, it is necessary to set all the parameters of the battery as shown in Figure 2.

Name	Expression	Value	Description
C_rate	0.5	0.5	C rate
Q_cell	280[A*h]	1.008E6 C	Battery cell capacity
I_1C	Q_cell/1[h]	280 A	1C current
kT_batt_ang	30[W/m/K]	30 W/(m·K)	Thermal conductivity, in...
kT_batt_r	1[W/m/K]	1 W/(m·K)	Thermal conductivity, cro...
Ea_eta1C	24[kJ/mol]	24000 J/mol	Activation energy
Ea_J0	-59[kJ/mol]	-59000 J/mol	Activation energy
Ea_Tau	24[kJ/mol]	24000 J/mol	Activation energy
T0	35[degC]	308.15 K	Reference temperature
J0_0	0.5	0.5	J0 at reference temperat...
tau_0	1000[s]	1000 s	tau at reference tempera...
eta_1C	4.5[mV]	0.0045 V	eta_1C at reference temp...
rho_batt	2000[kg/m^3]	2000 kg/m^3	Battery density
Cp_batt	1400[J/(kg*K)]	1400 J/(kg·K)	Battery heat capacity
ht	30[W/m^2/K]	30 W/(m^2·K)	Heat transfer coefficient
T_init	25[degC]	298.15 K	Initial/external temperat...

Fig. 2. Parameters of the LF280K Rechargeable Battery

The physics of the processes was specified by the Lumped Battery block, which included the Cell Equilibrium Potential block and the Voltage Losses block.

After the physical model was created, a finite element mesh was applied to the modelled model for finite element modelling. The maximum size of the mesh element is 0.04 m and the minimum size is 0.0072 m. The maximum height of the mesh element is given by coefficient of 1.5 and curvature coefficient is 0.6.

As a result of the calculation, data on the change of battery voltage during the charging process (graph shown in Figure 3) and the change of temperature of the battery itself (graph shown in Figure 4) were obtained.

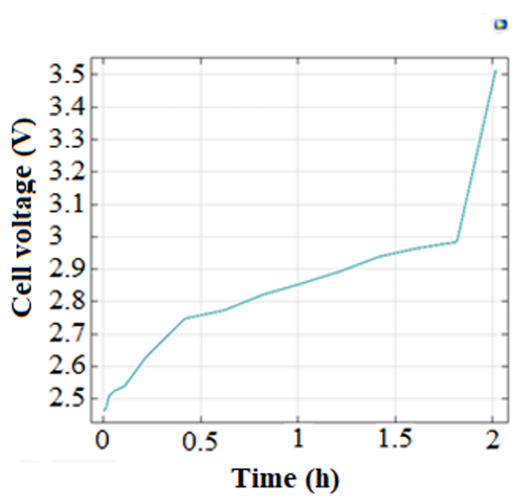

Fig. 3. Voltage graph during recharging of the battery

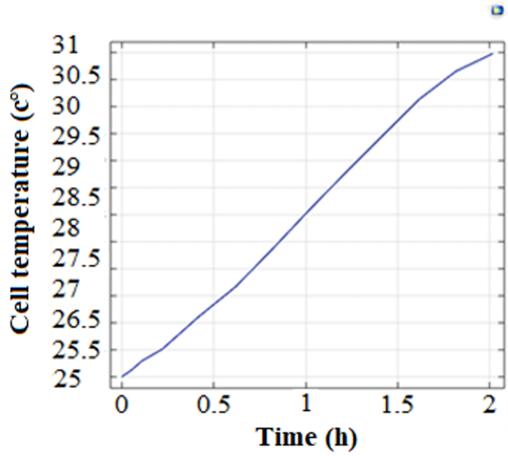

Fig. 4. Temperature graph for battery recharge

In this way, a module model is obtained that can be scaled for the thermal calculation of the entire unit.

1.2 Block simulation to obtain a graph of the temperature change during the battery charging process and the average air temperature in the block.

A 3D geometric model of the MECU was created in the COMSOL software package to perform the thermal analysis.

The main materials selected for the thermal analysis of the complete unit are: Air - air space in the unit (similar to the unit in COMSOL software - Air), Battery material - batteries, terminals (Active Battery Material), Polypropylene - thermal insulation (Polypropylene), Steel - container material (Structural steel).

After creating the physical model, a finite element mesh was applied to the modelled model for finite element modelling. The maximum size of the mesh element is 1.42 m and the minimum size is 0.265 m, the maximum height of the mesh element is set to 1.5 and the curvature factor is 0.7.

Based on operational considerations and analysis of the results obtained in COMSOL software (screenshots of the program are shown in Fig. 5, at t_{ext} = –60° and initial t_{block} = 20°, where a - without insulation; b - 50 mm insulation; c - 100 mm insulation; d - 200 mm insulation) during modelling, it is concluded that the use of 100 mm thick insulation is sufficient to maintain the storage temperature (not operation) of the battery. At 200 mm the average block temperature is higher, however, the implementation of such a solution is not economically justified (the standard method of applying polyurethane foam is 100-150 mm) and technologically more complicated (thermal insulation will be applied from the outside).

If we analyse the values related to the battery temperature, we can conclude that the operating temperature range is not respected and heating must be implemented. Preliminarily, during the design phase, an air-conditioning system with a capacity of 20 kW was selected. In COMSOL software, heating is simulated by adding a Heat Source unit (20 kW).

Results were obtained for the temperature change (graph shown in Fig. 6), with heating operation for the most critical case (at outside temperature t_{ext} = –60° and the internal starting temperature of the unit $t_{block\ init}$ = 0°).

Thus, based on Fig. 6 it can be concluded that operation of the MECU without heating is not possible, as the average temperature in the unit becomes less than 0° already after 3

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hours of operation, hence the normal operation of the battery will be disturbed. A heating capacity of 20 kW is sufficient, as the resulting maintain temperature of 10° corresponds to the operating range of the rechargeable battery.

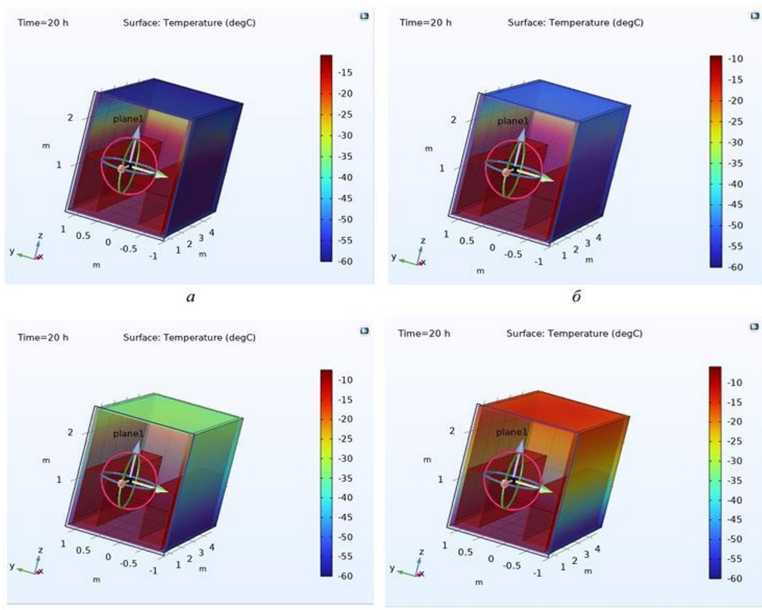

Fig. 5. Temperature distribution inside the container after 20 h

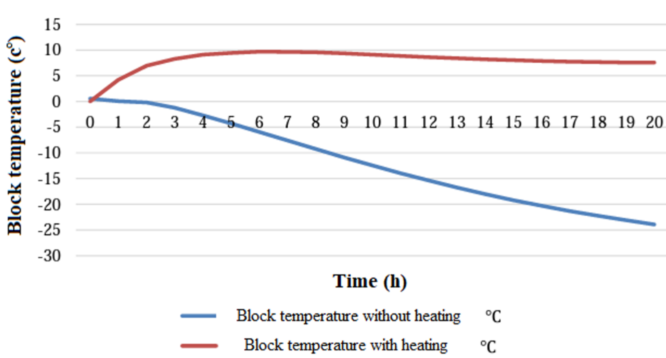

Fig. 6. Dependence of average container temperature including heating

Cooling must also be implemented to maintain the operating temperature range. Cooling is modelled with the Temperature (0°) block. The results of the temperature variation (graph shown in Fig. 7) are presented for the cooling operation for the most critical case (external temperature 40° and internal temperature 20°).

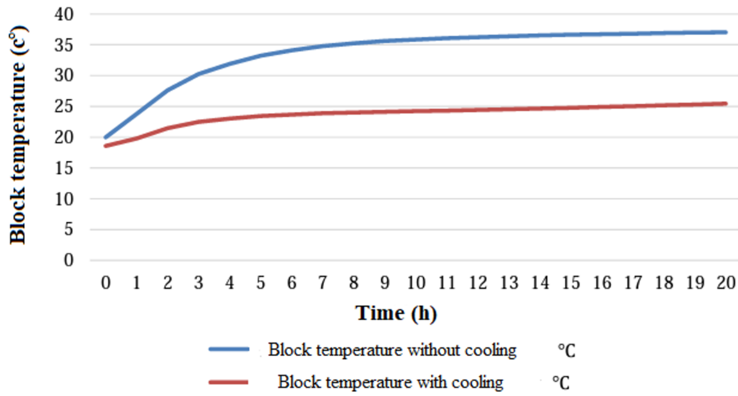

Fig. 7. Dependence of average container temperature including cooling

The results obtained show that without cooling the average block temperature exceeds the value of 35 ° already at 7 hours of MECU operation, which is outside the operating range of the battery, while the similar indicator when using a cooling system does not exceed 25 ° and indicates the effectiveness of the latter.

As a result of the thermal calculation for the MECU under development, results were obtained by means of finite-element modeling in the COMSOL software, which confirm the possibility of maintaining the operating temperature of LF280K at external temperatures corresponding to the climatic design group UHL1 according to GOST 15150-693.

2 Conclusions

Electric vehicles are one of the main trends in the world today, but in Russia there are serious obstacles to the development of this area, in particular the underdeveloped charging infrastructure for electric vehicles. A solution to this problem could be the use of MECUs.

At the stage of the technical design, there was a difficulty with the testing, and it was decided that part of the testing would be carried out through modelling, namely confirming that the MECUs meet the climate group (UHL1).

COMSOL software was selected for modelling, which allows thermal and strength calculations to be carried out. The initial step was to create a module of four MECUs for verification based on the manufacturer's data. Next, preliminary conformity with GOST 15150-697 was checked for UHL1 version. In this implementation, MECU should operate in the temperature range of -60 ° to 40°, and the most dependent equipment on the environment are the batteries (0~35°). Based on the simulation data, it is found that the minimum insulation thickness to create the battery storage conditions is a value of 100 mm. The pre-selected heating (20 kW) and cooling system (maintaining 0°) are also tested, and the results are satisfactory for battery operation.

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