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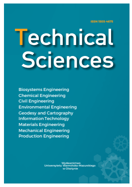

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THE METHOD OF DEVELOPING THE POWER SUPPLY SYSTEM FOR ELECTRIC RENTAL GO-KART

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Abstract

This article presents the results of work related to the power supply system for 10kW electric, rental go-kart. The research took into account a few types of battery cells. For the case study, the best option was chosen taking into account the restrictions included in the multicriteria analysis for further application. Chosen BLDC motor and battery type were tested on test stands and simulated in MATLAB/Simulink. Simulation model allowed to compare the characteristics from test stands and simulation and next tune the model. Minimum capacity of the batteries had to allow for at least 20 minutes of drive. Chosen elements: electric motor, motor controller, battery cells, BMS allowed to build the first prototype. Tests in real conditions showed the difference between simulation and research system. We could notice what to improve to tune the simulation model and the kart power supply system.

Introduction

Electric vehicles are gaining increasing popularity. This kind of vehicle is not only the cars but also vehicles used in the entertainment industry – skateboards, buggies, and go-karts (SANDEN, WALLGREN 2014). In rental go-karts, one race lasts from 8 to 15 minutes. The power supply system should be designed

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to ensure the drive for at least one race. Currently, on the market manufacturers offer electric go-karts (Blue Shock Race, Praga Global, OTL kart). Their offer includes several options of motor power and battery capacity. Several vehicle configurations allow to customize the go-kart for the buyer. Different models allow for better adaptation to the track, thanks to which the number of tracks with electric vehicles increases (Go-Karting Prague, Pitlane, Racing Center Warsaw).

Li-Ion cells are the most common used batteries in the electromobility (Miao et al. 2019). They are used mainly due to the high energy and power density, long life cycle and no memory effect. For transport application the most frequently used battery cells are: NCA (Lithium Nickel Cobalt Aluminum Oxide), NMC(Lithium Nickel Manganese Cobalt Oxide), LFP (Lithium Iron Phosphate), and LTO (Lithium Titanium Oxide). Figure 1 compares different types of Li-Ion batteries used in the EVs (Electric Vehicles) (Miao et al. 2019).

In battery cells can be distinguished three main shapes: prismatic, cylindrical and pouch (Horiba 2014). Cylindrical cell has good mechanical strength, specific energy, and energy density. Disadvantage of cylindrical cell is bad heat management. Prismatic cell has good mechanical strength, heat management, specific energy, and energy density but they have heavy shell, which leads

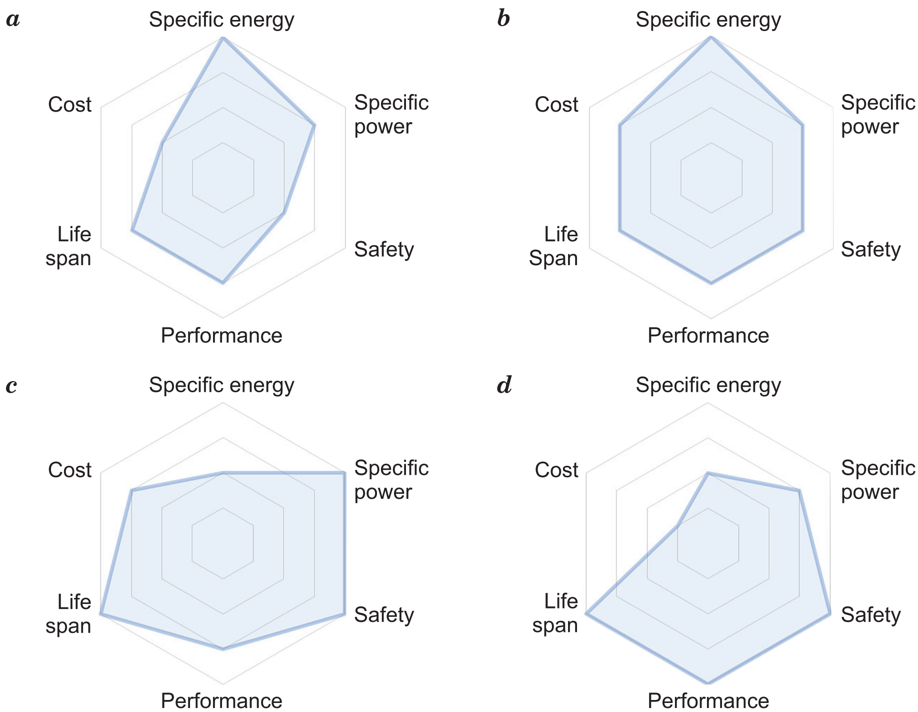

Fig. 1. Comparison types of battery cells: *a* – NCA, *b* – NMC, *c* – LFP, *d* – LTO

to certain restrictions on the energy density of the battery pack. Pouch cells has good heat management, energy density, and specific energy. Disadvantage is low mechanical strength (MIAO et al. 2019).

To manage the operation of each cell, the batteries are integrated with the Battery Management System (BMS). Its purpose is to control the work of cells by evenly charging, discharging, checking the State of Charge (SoC), and balancing the voltage difference between all battery cells (BRANDL et al. 2012). Drives used in electric vehicles are both DC (Direct Current) and AC (Alternating Current) motors. Currently, the most frequently used drives in electric vehicles of medium and high power are BLDC (BrushLess Direct Current) motors (DUER et al. 2013). These motors have many advantages, incl. no brushes, easy to control – rotational speed adjustment, high efficiency, and reliable operation.

The aim of the work was to develop a power supply system of the electric go-kart with the help of simulation model and the test stands. The decision was made to use the Model-Based Design (MBD) method (NIESTRÓJ et al. 2020, MATEJA, SKARKA 2020) to prepare the simulation models of power supply system and drive system. The aim is also to gain knowledge about the limitations, possibilities, and the degree of help of simulation models in the initial design and conceptual work of electric vehicles (EVs).

Electric kart concept

One of the problems that occurs in the case of electric vehicles is the limited capacity of the batteries, which results in a limited driving time (GOŁĘBIEWSKI 2018). The purpose is to ensure long operation time, quick charging, and reduce the mass of the vehicle. These requirements are often contradictory. The first way is to increase the parallel connection of the battery cells. This kind of connection can increase the driving distance but also will increase the mass of the whole vehicle (BARONTI et al. 2014). In a go-kart, which has small dimensions, there is not much space to attach a large number of battery cells. Racing vehicles should be also as light as possible, therefore this method seems to be disadvantageous. Another possibility is the use of battery cells with high charging and discharging currents (DI LECCE et al. 2017). Go-kart races in rentals usually last from a few to several dozen minutes. After the race, the battery cells will be connected to the charger and will be recharged to full capacity in a short time. This way does not require increasing the spare batteries and it will decrease the cost of battery packs. Batteries have also limitations like lifespan, decreasing the efficiency over time or charging infrastructure. This last will increase the cost of the whole infrastructure. The last method which was considered was the modular structure of the battery (ADEGBOHUN et al. 2019, SARKER, PANDŽIĆ 2013). It is necessary to design the battery pack in this way to enable quick assembly and disassembly. A modular structure significantly speeds up the time of service delivery and servicing subsequent customers who want to use the kart service.

The work began with the construction of the power supply system operation diagram which takes into account the drive system and other energy consumption sources. Parallel to this work, space for all components was sought. It was decided to place the batteries symmetrically on both sides of the vehicle to evenly distribute the weight of the cells on the frame of the go-kart. In the rear part of the kart, it was decided to put only the electric motor, motor controller, and BMS (Fig. 2). Placement each element in a separate position, in particular the BMS and battery cells, will allow for easier assembly of the whole in the initial phase and in the event of correction, faster changes to the first prototype (Fig. 3).

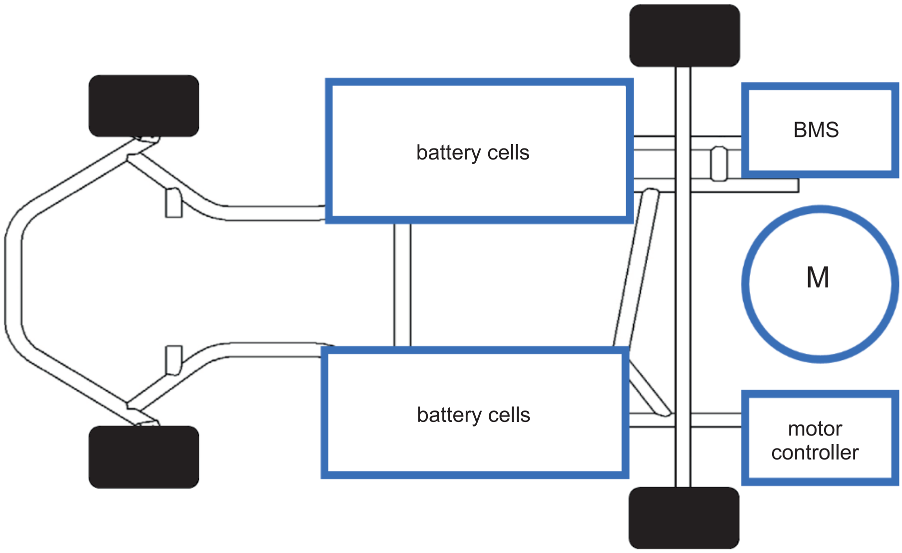

Fig. 2. The arrangement of the power supply system elements on the go-kart frame

Fig. 3. The first go-kart prototype

On the stage of the designing the concept of the prototype EV it was essential to make a decision of the battery cell type. It was decided to use LTO cells for the electric kart prototype. Disadvantage of LTO is cost of this battery, but advantage is lifespan, safety, wide working temperature range, and high discharging and charging current. The initial assumptions of the electric, technical parameters, and chosen elements of the kart prototype are presented below.

– BLDC motor: Golden Motor HPM-10KW;

– BLDC motor controller: Golden Motor VEC500

– battery cells: Yinlong LTO, nominal voltage of single battery cell: 2.4 V, battery cell capacity: 40 Ah, connection: 20S1P, max. discharge current: 10 C, rated voltage of battery pack: 48 V;

– estimated working time: 20 minutes.

Methods and materials

Modeling method of the simulation model

BLDC motor simulation model was described by two equations. These equations describe the electrical (1) and mechanical (2) part (HUGHES 2006).

$$U_s = R_s i_s + L_s \frac{\mathrm{d}i_s}{\mathrm{d}t} + k_e \omega_R \quad (1)$$

$$k_m i_s = B\omega_R + J\frac{\mathrm{d}\omega_R}{\mathrm{d}t} + M_s \quad (2)$$

where:

U_s – supply voltage,
R_s – stator resistance,
i_s – stator current,
L_s – stator inductance,
k_e – motor velocity constant, where: $k_e = U_s - R_s i_s$,
ω_R – rotor rotational speed,
k_m – motor torque constant,
M_{Sn} – nominal torque,
B – viscous friction coefficient, where: $B = k_m i_s - M_{sn}$,
J – rotor inertia,
M_s – load torque.

The battery discharge model was developed based on a ready-made library that was modified respectively for LTO battery cells. Model allowed to carry out simulations that will show how the battery will behave after being loaded with set current values. Both models (motor and battery) was more precisely described in article (MATEJA 2021).

Test stands

To compare the simulation model with the real environment conditions the test stands were built. BLDC motor were tested on the dynamometer. The batteries were tested with bidirectional programmable DC Power Supply. Due to the impossibility to check the equipment in the whole range of work (the research infrastructure was not able to work with such high currents) some characteristics were obtained thanks to the manufacturer of motor and batteries.

Fig. 4. Test stands

Results and discussion

Comparison of simulation and test stand characteristics

BLDC motor simulation characteristics were similar to the results from the test stand. Comparison the motor characteristics are presented in the Figure 5.

The characteristics of the battery simulation model were did not coincide with the results of the test stand mainly at the end of the characteristics. The simulation of the power supply system idealized the battery discharge model. Figure 6 presents the results for different discharge currents.

The first prototype

Integrating the entire power supply system with a power unit is a time-consuming and complicated process. The first problem occurs during the connect all components to the motor controller and after the first rides. After a few minutes from start kart voltage dropped to the level that if the throttle were maximum push the voltage dropped sharply below the minimum level, which cut off the power supply. Minimum operating voltage of the motor controller was 38 V. Power cut-off situation is dangerous, especially in the case of a desire

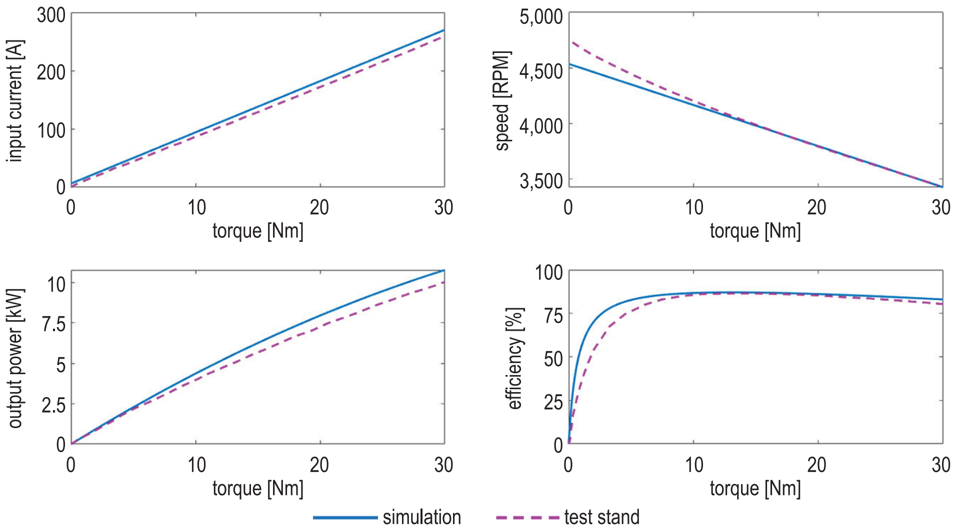

Fig. 5. Comparison of the motor characteristics

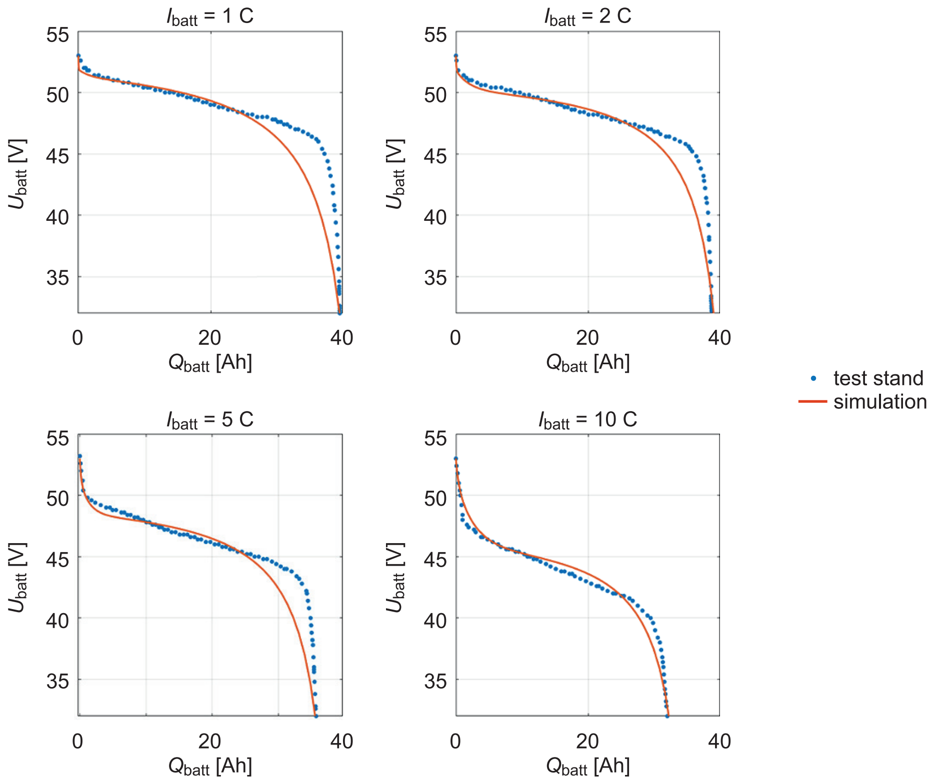

Fig. 6. Comparison of the batteries characteristics

to accelerate quickly, e.g., in the event of danger on the track or in the event of a desire to overtake another vehicle. Such an undeveloped power supply system could pose a threat to drivers. Current-voltage characteristics of voltage drop is presented on Figure 7. Characteristics was obtained by gradual increase in current load by the go-kart in 100% SoC.

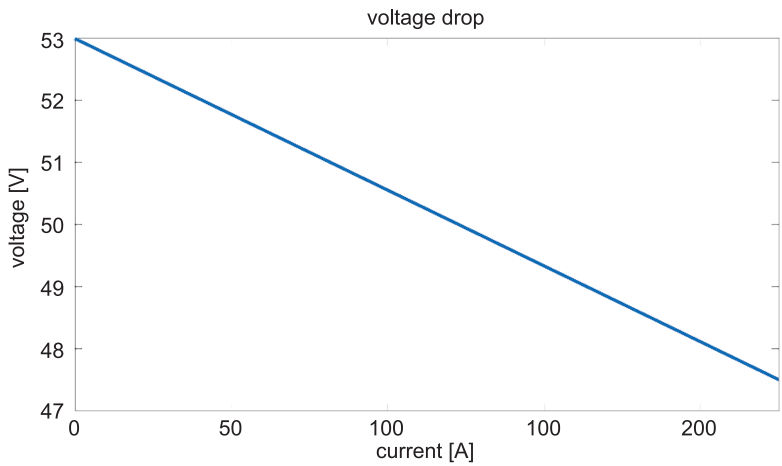

Fig. 7. Voltage drop characteristics of the full charged LTO battery

To solve the problem related to the blocking of the drive system, it was decided to check the possible development paths. The first was related to the use of a less powerful electric motor 3 kW or 5 kW. The controller could be reprogrammed to operate such an electric motor. The batteries and BMS would remain unchanged. The disadvantage of such a solution is a reduction in power, which would significantly limit the kart driving dynamics.

Another option was to increase the battery capacity to obtain a lower battery voltage drop. The downside of this solution is the need to complete a second set of the same type. This would generate both costs and increase the weight of the entire system and vehicle.

The last alternative was to increase the system voltage. By checking the documentation of the motor controller and introducing changes to the software, it was obtained that the maximum voltage at which the controller and the electric motor can operate is 72 V. At the same time, it was checked that the BMS system can manage a maximum of 24 cells. Increasing the voltage seemed to be the most advantageous option. Add of more cells in series, unfortunately will not reduce the voltage drop. However, it will extend the time it will take for the voltage to drop to minimum level. It was decided to add an additional 4 cells to increase the voltage and battery capacity. New battery pack consisted of 24 LTO cells connected in series. The use of a larger number of cells caused a problem regarding the location of additional batteries on the go-kart frame. New module was placed in the front part of frame in the place where the fuel tank is located in the gas karts (Fig. 8). Placing an additional battery pack in the front of the vehicle will add extra weight to the front of the vehicle, which is lighter than the rear. This will increase the grip of the front wheels, which transfer directly into go-kart control.

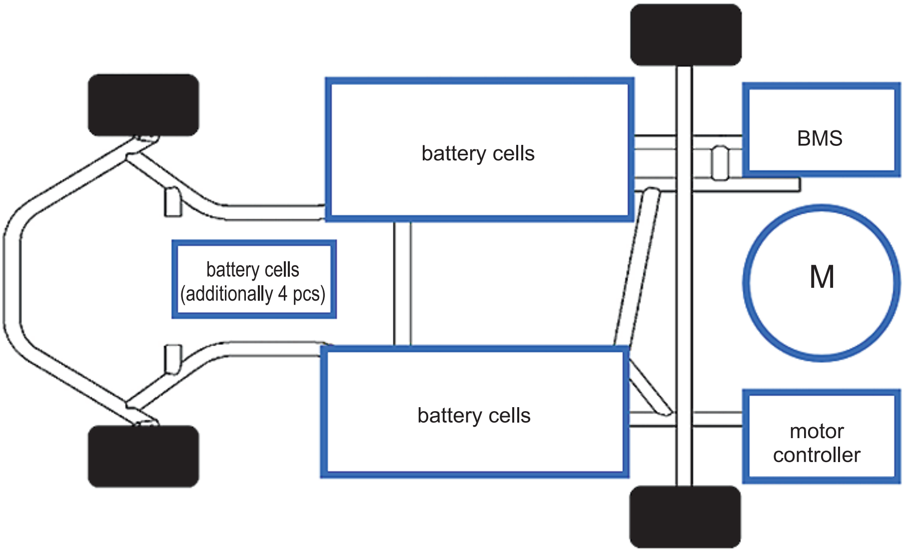

Fig. 8. The new arrangement of power supply system elements on the go-kart frame

The second prototype

Add of the four battery cells allow to increase the nominal voltage from 48 V to 57.6 V. The voltage drop was this same as in the previous configuration, but there was no more power shortage problem. New configuration of the power supply system allowed to test the kart for a longer time on the track. Power unit was able to work the first time more than over a dozen minutes. It caused that high current values heat up motor controller. The controller has a protective function that protects it from overheating so the software blocks the work of the system. Due to the overheating of the controller, it was necessary to use a cooling system. The heat sink and the fan performed their function (Fig. 9). There was no need to use a liquid-cooled system.

Tests were in the indoor karting track (Fig. 10), and it allowed to check the proper work of the power supply system, drive system, steering system, and also make changes to the vehicle.

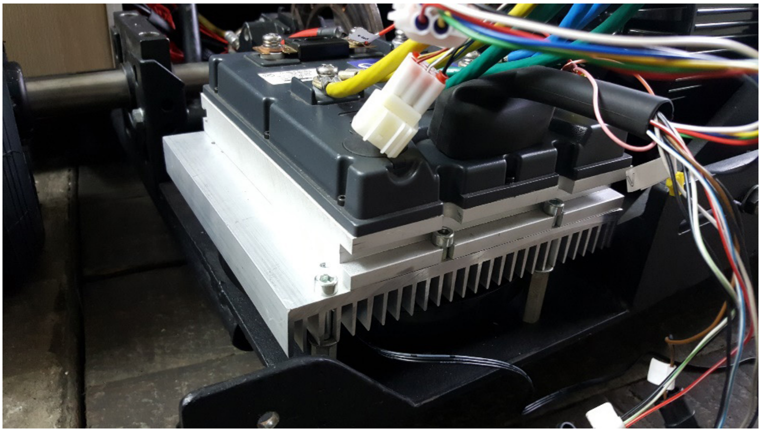

Fig. 9. Motor controller heat sink

Fig. 10. Electric go-kart prototype on the indoor track

During the tests electric go-kart was able to drive over one hour in the 750 meters track with a straight line 60 meters long and 23 turns (S-kart). The specificity of the track and numerous turns enabled the use of energy from braking recovery and the time between charges has been extended. Different construction and parameters of the track may change the driving time, distance traveled. During the test run on the track, the maximum speed was 45 km/h, while on the 100-meter straight, go-kart was able to achieve the speed 75 km/h.

Tests have shown that for tight tracks with a large number of turns, the gear ratio should be increased, because the go-kart accelerates slowly and the maximum speed is impossible to achieve on this type of track.

Conclusions

Designing the power supply system of electric vehicles is a complicated process which must consider a number of constraints both from the external environment and also from the parameters of the vehicles themselves.

Simulation model idealized the reality and do not consider the outside restrictions. Simulation models were based on the two separate systems. To configurate kart power supply simulation model it should be integrate separate model of drive unit, battery with the BMS, and control unit to one EV's simulation model. Only the including all components in the model will allow for greater control and correct operation of the simulation.

Design, build, and verification of the electric kart allowed to know the strengths and weaknesses of the power supply system, simulation model, construction, and more. The direction chosen in advance is not always the right one and at various stages different methods may be disappointing or helpful. In the case of building prototypes, the most favorable seems to be the assembly of the structure and its verification. Simulation models are the next step. To develop them, it is needed to have some initial knowledge, which can then be used as input data for the model.

Tests performed on the indoor karting track allowed to verify the correct operation of the power supply system. Some of the problems appear during the kart driving. There is no possibility to prepare good simulation model without the build the test stands or prototype. First simulation model should be tuned with the data from test stands, prototype data, verification tests data. Such tuned model can be the base for the further intended use system.

Performed simulation model will be integrated with all systems included in the electric kart. The model prepared in this way will be able to form the basis not only for racing vehicles, but also for other electric vehicles.

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