COMPLETE TRACTION ELECTRIC EQUIPMENT SETS FOR HYBRID BUSES

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Introduction

The analysis of world tendencies of development of transport systems displays, that technology development moves in a direction of energy and resources economy and creation of vehicles with ecologically safe parameters. Importance of application of ecologically pure, energy-saving vehicles in megapolises of Russia is obvious.

Competitiveness in comparison to traditional and hybrid vehicles of foreign manufacturers becomes the basic criterion in creation of new domestic transport techniques. From the analysis of set of alternative variants it follows that nowadays a real possibility to create ecologically pure (or, at least, environmentally safe) and competitive vehicle is application of combined (hybrid) power train (HPT) on the basis of combustion engine, generator, traction electric drive with a buffer storage. In hybrid power trains it is possible to combine positive properties of separate power sources: high specific energy of an energy source and high specific power of a buffer power source. Priority designs are HPTs with combustion engines, while in the long term perspective – HPTs on the basis of fuel cells. Efficiency of HPT application with a buffer storage, basically, is higher, if repeat of acceleration and braking in the standard road cycle of a vehicle is more often. Typical example of the vehicle which movement is characterized by repeated accelerations and braking is a city shuttle bus which during the movement in a city stops not only by a signal of traffic lights, but also on bus stops for drop-off and boarding of passengers.

Efficiency of HPT application is caused by:

– the big difference of the average and peak power demanded for movement (a ratio of powers is 1:5 and more);

– the big difference of specific values of available energy and power sources onboard the vehicle.

An important factor of lowering of fuel consumption is recuperation of energy of braking instead of its thermal dispersion, and operation of the ICE in a stationary fuel-effective mode, which considerably reduces the value of toxic exhausts of the ICE. Operation of city buses with the a huge number of stops gives perfect conditions for consumption of the braking energy. Buses basically are used at low speeds and very often accelerated, that just almost at once to brake and stop. In usual buses the kinetic energy basically will be transformed into unapplied heat, while in hybrid buses accelerate after stops, consuming only the electric energy regenerated from the stored braking energy. Up to 45 % of all the time of operation of city buses falls on stops where the automatic start-stop system helps to save an expensive fuel.

Hybrid buses in the world

The specified advantages are known for a long time to the world manufacturers of buses. Therefore it is not a casual thing that sales of serial hybrid city buses have begun in 1991. The pioneer here – as well as in advancement of passenger hybrid cars – was Toyota Corp., which affiliated company Hino had released a hybrid city bus Hino Blue Ribbon City Hybrid. The bus has been supplied by the Hino's own development – a parallel hybrid drive train HIMR, where a 5-step gearbox was combined with the asynchronous motor-generator, and NiMH batteries were used as the energy storage. Since 1997 and until now the leader in number of commercially operated hybrid buses are the USA and Canada. Only in the USA more than 6000 hybrid buses of various manufacturers have been sold. And it was possible to diminish a little a difference in the price of the hybrid and usual bus. For example, in 2007 the most mass American hybrid bus Orion VII Hybrid cost was US$ 385 thousand, and its CNG analogue's cost was US$ 313 thousand. In its basis was the series hybrid drive train created by American-British aerospace and weapon corporation BAE Systems. The system includes a synchronous generator with permanent magnets and an asynchronous traction motor in set with IGBT power converters, controller and lead-acid batteries by Hawker. Electric machines and the power converter had an oil cooling, and the controller had a water cooling. It is necessary to note, that since 2008 the second generation of systems of hybrid traction drive by the BAE Systems is already on sale. They are distinguished by application of a more environmentally clean diesel engine (Euro-4 with EGR), a united oil cooling system of all components of the drive and new controller software. Lead-acid battery was replaced by lithium-ion battery from A123Systems. Other manufacturers of buses - Canadian corporation New Flyer, British Alexander Dennis also use the series hybrid drive train by BAE, and the Japanese Isuzu tests the new bus Erga (9-m class) with hybrid drive from BAE Systems as well.

In the USA and Canada active money and organizational support for introduction of innovative and harmless city buses is rendered by the authorities of all levels and socially-commercial associations and organizations. Large cities of the USA and Canada buy hundreds of such hybrid buses. Therefore now over 2200 of such buses are already in maintenance and not less than 850 pcs. are planned to be delivered to the customers in the near future (2010-2011). Ownership costs were made equal and even lower that of the gas (CNG, LPG) buses which earlier were considered as cost effective and more ecology-friendly alternative to a diesel buses. The following example is characteristic. The authorities of New York have refused purchasing of about 200 gas buses, having directed the money reserved for purchase of hybrid buses. After that the authorities have made a decision to shift completely to purchase of hybrids, stressing that at similar ecological characteristics diesel-electric buses are more cost effective and give essential advantages in maintenance and comfort, do not demand an additional infrastructure, and the difference in the price is payed back quickly enough.

The basic companies manufacturing a complete traction electric equipment sets of various types for hybrid buses are:

– General Motors /Allison Transmission (common development with Daimler Chrysler and BMW) with $E^{P}40$ and $E^{P}50$ split series-parallel hybrid drive trains,

– Eaton with Fuller® UltraShift® Hybrid parallel hybrid drive train,

– Toyota (Hino) with HIMR I and II split series-parallel hybrid drive trains,

– Volvo Trucks with I-SAM parallel hybrid drive train,

– Voith Turbo with ELVO® series hybrid drive train,

– Mitsubishi Fuso with series hybrid drive train (only for the Japan market),

– Vossloh Kiepe with series hybrid drive train,

– Siemens Automation&Drives with ELFA® set for series hybrid drive trains (applied by the American ISE Corp. in a set of series hybrid drive trains under the ThunderVolt® trademark),

– BAE Systems with HybriDrive® Gen. I and II series hybrid drive trains,

– Enova Systems with CEU 90, 120, 240 sets for series hybrid drive trains,

– E-Traction with a set of TheWheel ™ motor-wheels for series hybrid drive trains etc.

From the mentioned above E^{P} from GM, ELFA from Siemens (with ISE), CEU from Enova and HybriDrive by BAE are the most widely used by many bus manufacturers.

Thus, about ten developers of complete traction electric equipment set (TEES) for hybrid buses exist in the world from which only the largest are mentioned in our review. The amount of manufacturers of separate components or groups of components, the companies-integrators is higher in about ten times. As to manufacturers of buses it is possible to say, that for them the presence of the hybrid bus in their production line is a “point of honor”. The manufacturer which does not have hybrid models, in the developed countries is considered as a kind of “second order” company. It is confirmed also by the large exhibitions of manufacturers of the transport, which took place in 2009 – the UITP in Vienna and BusWorld in Kortrijk.

As to Europe – here the 2010 should become a critical year, in which a collection of models of hybrid buses from leading manufacturers comes into mass production – MAN City Lion’s Hybrid, Volvo 7700 (single- and double-decked), Scania Omni city Hybrid, Mercedes Citaro Hybrid, Solaris Urbino Hybrid (the second generation), a number of models from Van Hool and VDL. At the same time, mass selling of variety of single- and double-decked models of the British manufacturers will begin in the UK (Wrightbus, Alexander Dennis, Optare).

LIAZ 529XX Hybrid Bus

Rapid development of hybrid vehicles in the world and perspectives of their development did not remain without attention of the Russian experts in this area. Several enterprises of “RUSELPROM” Corp. simultaneously develop and prepare manufacture of electric machines, power and control electronics, test benches for acceptance and qualification trials of both components and overall sets of a traction electrical equipment for electric drive trains intended for various vehicles: large haul trucks, multicoupled truck-trailers, multi-axis wheeled tractors, agricultural and industrial wheeled and tracked tractors. To this list one more direction – the hybrid bus – was added. For the task of development of electric drives for vehicles in the corporation the “RUSELPROM-ElectricDrive” Ltd. has been organized. It is a special division of the “RUSELPROM” Corp. which activity is R&D, manufacture, tests and serial production of complete traction electric equipment sets of hybrid and electric drive trains for vehicles on the basis of advanced techniques of project and manufacture as well as advanced power and control electronics. As a test base serves the scientific research institute “NIPTIEM” which is a part of “RUSELPROM” Corp. At the International Automobile Forum in Moscow, 9-12th of September, 2008 “GAZ-Group” has presented the city bus LIAZ 5292XX with hybrid power train (Fig. 1). Bus LIAZ 5292XX is a result of teamwork of “RUSELPROM” Corp. and the “Likino Bus Works” of “GAZ-Group”. TEES for the bus was developed by “RUSELPROM-ElectricDrive” Ltd. It is the first Russian bus with the hybrid drive and no one more from domestic manufacturer has analogs of it.

Figure 1: LIAZ 5292XX bus (prototype) with a hybrid drive train at International Automobile Forum (the KROKUS-EXPO epicenter, Moscow, September 9-12th, 2008).

Main expected advantages of the hybrid drive for the city bus:

– up to ten-fold decrease of the emission level, especially in urban conditions (Euro-V level);

– operation of the diesel engine in optimal modes in terms of fuel efficiency and emissions;

– fuel savings of 25-50%;

– the possibility to start a diesel engine from the power storage without separate belt-driven starter motor;

– the possibility to generate and recuperate the electric power;

– reducing of diesel engine power by 25÷30% with keeping the same torque on wheels;

– increase of bus comfort (noise, vibration, steering response);

– increase of bus reliability and operational life;

– the most passenger-friendly riding (smoother starting and braking), caused by the absence of the power-shifting with interrupt of the power flow from the power train to wheels.

The primary tasks of the development were:

– shaping the reasonable structure of family of LIAZ hybrid buses;

– creation of the technical reserve necessary for organization of the manufacture of hybrid buses at the enterprises of the "LIAZ" LLC (with possible participation of the European partners);

– shaping the necessary industrial cooperation and check of its ability to mastering and regular deliveries of HPT and its modifications;

– estimation of basic economy parameters of the HPT and the expenses necessary for organization of the manufacture;

– creation and working off a prototype, providing a full cycle of operation in city conditions during pre-production;

– practical check and improvement of the basical technical decisions by development, manufacture, and by research, acceptance and operational trials of pre-production models of buses with HPT.

For achievement of the demanded characteristics of movement in a city (NAMI-II road cycle) traction equipment of the bus should provide the following values (estimation of the traction-dynamic model): average power for the movement in the city is 33 kW; maximum (peak) power is about 250 kW; at high-speed movement (90 km/h) the track effort should be 5000 N, power of 115 kW is required; at movement on 20% (12°) grade with a speed of 10 km/h (13 t. of mass, 30 sec.) traction effort is 29,000 N, power is 80 kW.

The TEES has a series configuration (Fig. 2). Choice of the series drive train configuration has been based on the world experience, minimal cost and time limits specified for design, rollout and cost considerations of the project. The substantiation of a choice of all TEES components is given in [1]. The basic parameters of power equipment of the TEES for LIAZ 5292XX bus are given in the Table 1. It is curious, that parameters of the TEES power equipment of such buses, as LIAZ 5292XX, Scania and MAN Lion´s City, having similar specifications in passenger capacity, mass and dimensions, have practically coincided. We shall mark thereupon, that traction-dynamic modeling, kinematic configuration choice, definition of the basic performances of TEES power devices, project and manufacture of drive train devices of LIAZ 5292XX bus were completed in "RUSELPROM" Corp. before data of foreign analogues have been published, which, certainly, confirms the objectivity of the estimations received.

Table 1: Parameters Of The TEES Of LIAZ 5292XX

Parameter	Value
Generator maximum output power,	132.5 kW
Maximum torque on generator shaft, (at 2200 rpm)	575 Nm
Maximum rotation speed of the generator shaft,	2200 rpm
Rated DC bus voltage	750 V
Traction motor maximum output power	250 kW
Traction motor continuous output power, up to	125 kW
Maximum (starting) torque on the shaft of traction motor	1500 Nm
Maximum (continuous) torque on the shaft of traction motor	1000 Nm
Maximum rotation speed of the traction motor (at the vehicle speed 90 km/h)	4975 rpm
Storage Capacity Voltage Stored energy Discharge current Maximum discharge current Weight Dimensions (LxWxH of each of 12 modules)	 21.0 F 400 – 800 V 1220 Wh 300 A 1500 A 700 kg 762x425x265 mm

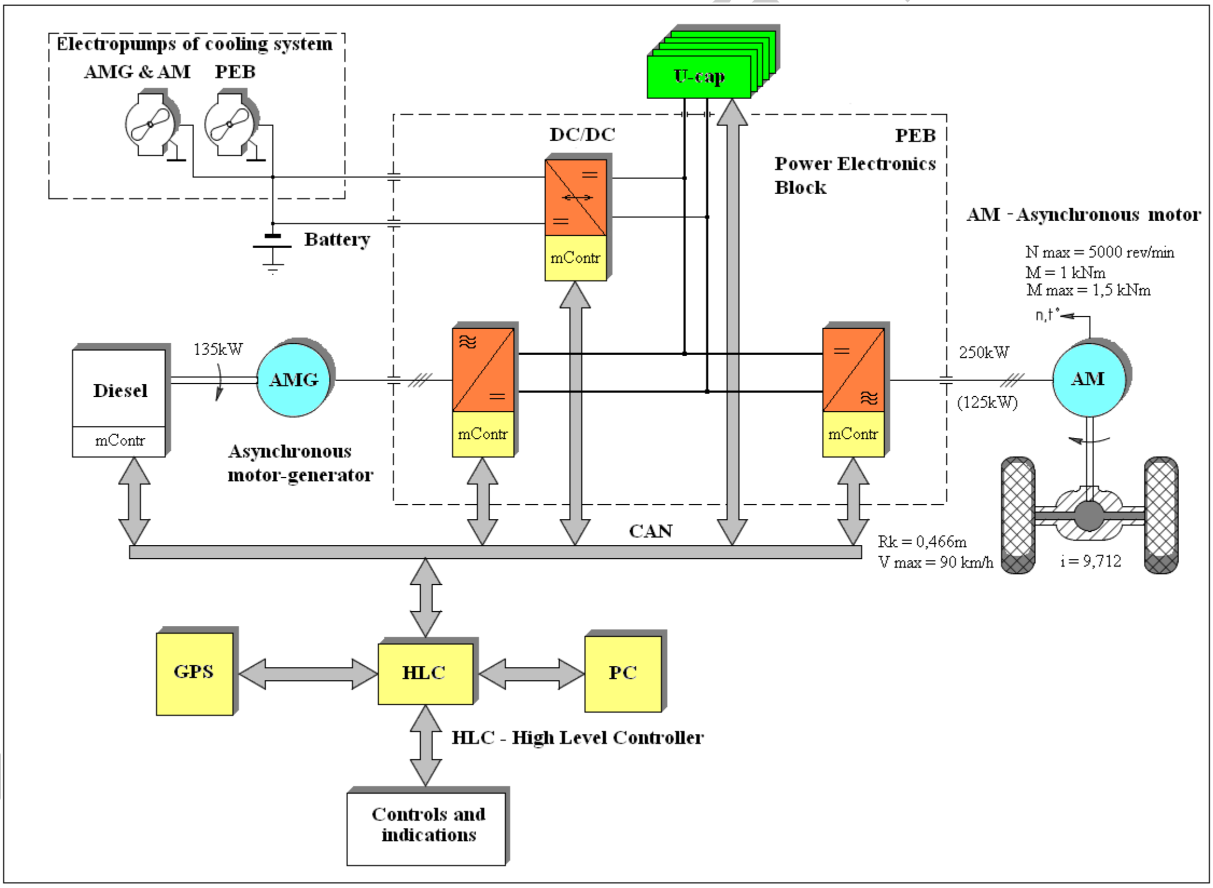

Figure 2: Block diagram of the TEES of LIAZ 5292XX bus

The complete set of traction electric equipment of the LIAZ 5292XX bus includes:

– asynchronous motor - generator (AMG);

– traction asynchronous motor (AM);

– power converters with a microprocessor control system (mCont) for AMG and AM;

– buffer storage unit based on ultracapacitors (U-cap);

– high level controller (HLC) for controlling power flows and the steering link with controls and information displays in a cabin of the driver;

– Auxiliary power supply system for TEES and a battery charge (DC/DC).

Power converters of AMG and AM are mady on base of integrated three-phase voltage inverter modules SKAI from SEMIKRON. Their maximum effective current per phase is 300 A (continuous), maximum DC-bus voltage is 900 V. Processor controllers TMS 320 with vector control system are applied for frequency control of electric machines.

The traction motor advances short-term power of 250 kW which exceeds the power of a standard diesel engine of a serial analog – diesel bus LIAZ 5292 (180 kW), ensuring a worthy dynamics at acceleration. Continuous power of the AM corresponds to that of AMG and ICE – 125 kW. Reduced (in comparison with an analog) power of a diesel engine used in the hybrid bus (Cummins ISBe4+185, 136 kW, Euro-IV) is enough for movement in a city cycle and uniform movement with speeds up to 90 km/h, and the lack of power at acceleration is compensated by the storage capacitor. At the same time de-rating of the power of a diesel engine is one of the components of fuel economy.

Another component of the fuel economy, possible for the series hybrid configuration, is optimization of a static mode of diesel engine. According to the power demand for traction AM such parity of ICE's torque and rotation speed is selected which ensures it's best fuel efficiency. Energy distribution is carried out by the control algorithm of power flows which provides the main fuel economy due to the following factors.

Firstly, power demanded for AM is divided on swiftly and slowly varying components, first of which is supplied by the buffer storage and the second is delivered by the ICE, which provides ICE operation in a mode, close to the stationary (toxic emissions of an exhaust is thus also minimized).

Secondly, the storage is able to collect the recuperation energy at braking, usually lost in mechanical brakes; it is especially important for rout (shuttle) vehicles with rather frequent stops (city buses).

Control of power flows is a function of HLC. It also realizes a traffic control, including logical processing of input signals of from driver's cab, sensors, measurement of analogue signals, control of movement conditions of the bus, and also processing and saving of emergencies. HLC has four independent CAN interfaces of data transmission, widely applied in motor industry. Two of CAN interfaces operate under CANOpen protocol and realize link with controllers of the motor-generator, traction motor, storage and drivers information panel with a rate of 1 Mbit/s. HLC receives all the necessary information through them and controls the components of the electric drive train. Third CAN port operate under SAE J1939 protocol with a rate of 250 kbit/s. The HLC is connected with the common board net J1939 of the bus and has a possibility to receive all information on condition of ICE, ABS and ASR controllers. Through the given communication channel HLC sends the setup of the ICE rotation speed. The control of the critical parameters and emergencies of the ICE is governed by the HLC. If one of parameters has overcome the admissible boundaries, or there is an emergency, HLC generates the notifying message on an information panel of the driver. HLC saves the state of all controls, final control devices (actuators), and software settings in the memory after each certain, rather small, time interval. At the maintenance point engineers can see all the sequence of operations of the driver. If an emergency occurs in the AMG or AM controllers, record of a corresponding emergency log in internal memory of these controllers is made; subsequently the information on emergency development is read out and recorded through the CAN channel into the HLC with an emergency code. HLC also saves its own emergency log which was previous to the emergency occurrence. It allows to have a full picture of conditions of all TEES devices for some seconds prior to the emergency, and to determine a cause of the fail. Emergency logs may be copied for their saving in the external storage; by means of SCS it is possible to receive graphs of behavior of parameters of the system before emergency.

For simplicity of diagnostics and service, adjustment and control of equipment parameters, “RUSELPROM-ElectricDrive” Ltd. has developed a service computing system (SCS) – special software for external personal computer. SCS allows adjusting settings of the control system, selectively visualizing current values of variables, saving and dynamically displaying them in operator-friendly form, providing navigation and visualization of emergency logs of the HLC (Fig. 8)

Specialists of the “RUSELPROM-ElectricDrive” Ltd. have developed the special software for diagnostics and service, adjustment and control of the equipment parameters – the Service Computing System (SCS) which is intended for visualization of parameters of TEES operating variables; presentation and processing of the graphic information; loading, saving and viewing in graphic and table form the files of emergency logs of HLC, AMG and AM. It can be installed on any personal computer (minimal requirements - Windows XP, 1.4 GHz or above, RAM 512 Mb, 100 Mb on a hard disk, one PCI-Express slot, two USB 2.0 slots). SCS is intended for visualization of parameters of operating characteristics КТЭО. The view of SCS display is given in the Figure 3.

Figure 3: Example of a display of the SCS.

SCS allows to simplify significantly the adjustment and control of the TEES, as well as the analysis of emergency logs which allows to accelerate search and fixing failures.

Benchmark tests of the electric equipment of LIAZ 5292XX bus

Before installation on the bus the set of a traction electrical equipment has passed adjustment and comprehensive investigation at the full-size test bench with the expanded structure of measuring instruments.

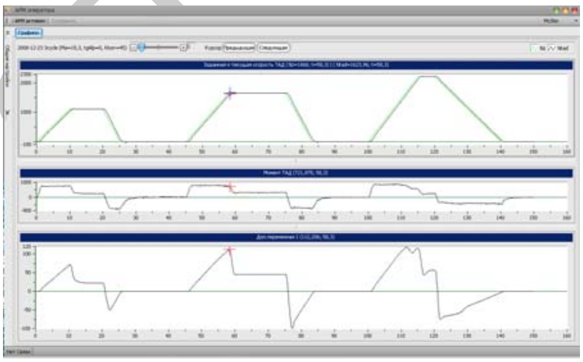

Fig. 4. Passing the test rout, consisting of three steps of acceleration

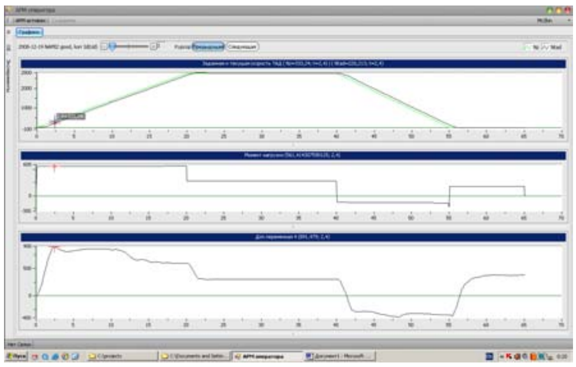

Fig. 5. Movement in the NAMI-II cycle

The few chosen test results are given in the figures.

On the Fig. 4 there are given characteristics of the test rout passing. The test rout consists of 3 acceleration regions (achieving 20, 30 and 40 km/h speed sequentially) which are finished by a full vehicle stop after the each one. On the Fig. 5 the NAMI-II test cycle passing is indicated (NAMI-II is the standard Russian city test cycle). The cycle contains acceleration up to 50 km/h within 20 sec while climbing up on the 2% grade. From the top characteristic it is clear that the reference motion speed (green line) is achieved (actual speed, black line), though the peak AM power demand (bottom characteristic) is significantly higher than the ICE-AMG power ability. Medium characteristic indicates the traction AM torque. Thus, the hybrid bus with the lower ICE power rating provides necessary acceleration rate without becoming an obstacle for the intensive city traffic.

Projects of development of the other city buses

Experts of “RUSELPROM-ElectricDrive” Ltd. had carried out traction-dynamic modeling and estimation of performances of basic power components of TEESes for a number of the various city buses which are produced by the enterprises of Russia, Ukraine and Belarus:

– 9-m class – PAZ-3237 (“GAZ-Group”), “Bogdan”;

– 12-m class – model 4202A (“Belcommunmash”), MAZ-203 (“Minsk Automobile Works”);

– 15-m class – model 627006 (“Volgabus”);

– 18-m class –LiAZ-6292, MA3-205.

Experts of “RUSELPROM” Corp. have execute projection of all components of a traction electric equipment: electric machines, power and control electronics, auxiliary power systems and cooling for various buses specified above. The enterprises of the Corporation are ready to manufacture complete TEESes.

As to versions of a buffer storage systems it should be marked, firstly, that “RUSELPROM” has worked out a version of application of domestic super capacitors.

Secondly, “RUSELPROM” has studies of application a Li-ion battery as a buffer storage.

Conclusions

By the results of the International Automobile Forum, Moscow, September, 9-12th, 2008 this bus has been recognized as the best bus of year in Russia.

Thus, “RUSELPROM” Corp. is ready for development, manufacture and delivery of the complete traction electric equipment for various city buses and delivery trucks in sets meeting the requirements of customers. The available developments are enough not only for execution of separate innovative projects, but also for modernization that is obviously necessary due to a variety of requirements and conditions of application of vehicles. Comparing parameters, structure and composition of TEESes of domestic hybrid buses and their foreign analogues, it is possible to claim with good reason, that the domestic enterprises – manufacturers of transport techniques are able in the shortest terms to achieve the advanced level in creation of a modern public municipal transportation of the new generation, there must be only a desire. Introduction of hybrid transport techniques may be a worthy example of an innovative way out from the crisis of the branch of transport machine industry. It is essential, that creation of energy-saving, environment-friendly vehicles is possible on the fundament of commerce, without engaging means of innovative support though, certainly, the financial and organizational help of the state authorities would not be excessive.

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