

Practical implementation of the concept of converted electric vehicle with advanced traction and dynamic performance and environmental safety indicators

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Abstract. The objective of the work presented in this paper is to describe the implementation of the technical solutions have been developed, with regard to structure, composition, and characteristics, for an experimental prototype of an electric vehicle which has been converted from a conventional vehicle. The methodology of the study results is based on the practical implementation of the developed concept of the conversion of conventional vehicles into electric vehicles. The main components of electric propulsion system of the experimental prototype of electric vehicle are developed and manufactured on the basis of computational researches, taking into account the criteria and principles of conversion within the framework of presented work. The article describes a schematic and a design of power conversion and commutation electrical equipment, traction battery, electromechanical transmission. These results can serve as guidance material in the design and implementation of electric propulsion system (EPS) components of electric vehicles, facilitate the development of optimal technical solutions in the development and manufacture of vehicles, including those aimed at autonomy of operation and the use of perspective driver assistance systems. As part of this work, was suggested a rational structure for an electric vehicle experimental prototype, including technical performance characteristics of the components of EPS.

1. Introduction

Advanced technologies in the field of machine vision and object detection, positioning and geolocation, actuators and software - this is an incomplete list of necessary components of an autonomous vehicle. However, the EPS is no less important component of unmanned transport of the present and future. Due to advanced technical solutions in the field of electric drive, voltage converters and traction batteries, the vehicle is fully capable of meeting modern standards and requirements with respect to operational safety, environmental and energy efficiency, as well as the criteria for the implementation of automated control. In other words, an autonomous (unmanned) vehicle of the future is predominantly an electric vehicle (EV).

In light of existing environmental problems, interest in EVs continues to grow as their use is devoid of polluting emissions and the clean energy they provide as an alternative compensates for the energy and resources that are necessary in their construction. Upgrading the existing fleet of vehicles currently in use, inclusive of passenger vehicles and taxis as well as vehicles for municipal and utility use, is feasible with the technology available today. This would include converting the current fleet of



internal combustion vehicles into ones with an electric drive. This article presents the full process and results of this implementation process of converting [1] conventional internal combustion vehicles into EVs based on experimental prototype of EV.

2. Aspects of practical implementation

2.1. *Aspects of conversion in electric vehicles and trends to solve them*

The design of electric propulsion systems for modern electric-accumulating vehicles is inseparably associated with the required operating modes and operational features of the vehicle. The parameters and characteristics of the latter depend strongly on the structure of the electric or combined power system as well as the layout constraints of the base motor vehicle.

The main problem in creating an electric vehicle based on the mass produced vehicles determines the complexity of EPS configuration on board in the vehicle. The limited space available for placement of electrical components and allowed weight of the base motor vehicle, along with the basic principles of conversion [1], necessitates the use of optimized technical solutions and perspective element base as well as modern technologies and materials.

The significant reduction in unladen weight of the vehicle can be achieved mainly through the use of modern element base. This mainly concerns the chemical power sources, traction electrical machines and converter equipment, which shall meet the high specific performance, including specific power, energy and torque.

The presence of the speed-change gearbox in the EV will lead to a decrease in the overall efficiency of the electromechanical transmission and will also increase the weight of the overall propulsion system. The optimal solution would be a direct electric drive scheme that excludes the use of the speed-change gearbox, which also opens up more opportunities to improve traction and dynamic characteristics of EV compared to the base motor vehicle as well as reduces the weight of the propulsion system, eliminates the step change in torque and speed on the drive axle. The scheme of stepless transmission is the basic technical solution adopted for further consideration and implementation in the experimental prototype of the convertible EV.

2.2. *Purpose and key characteristics of experimental prototype of electric vehicle*

As part of the discussed project, the experimental prototype of electric vehicle converted on the basis of the car, should be considered as an object for implementation of the full technological cycle for conversion of conventional vehicles into electric vehicles.

The main design and technical and operational parameters implemented in the experimental prototype of EV include:

- a) gross weight of no more than 1.75 tons;
- b) wheel circuit of 4x2;
- c) type of drive as rear wheel drive;
- d) transmission is designed as stepless transmission (without use of gearbox);
- e) type of electric power source is battery pack, based on lithium-ion battery cells;
- f) type of traction motor-generator is the permanent magnet synchronous motor;
- g) braking system is a standard system with use of electric braking and possibility of power regeneration;
- h) type of traction motor cooling and a power voltage converter is liquid type;
- i) maximum power of the traction motor-generator is not less than 140 kW;
- j) peak allowable torque on the shaft of traction motor-generator is 700 N·m;
- k) nominal voltage of electric power source is 360 V;
- l) rated energy reserve of traction power source is 28 kW·h;
- m) stand-alone driving range with zero toxicity is over 120 km.

The engine room of experimental prototype of electric vehicle is shown on figure 1.



Figure 1. The engine room of experimental prototype of electric vehicle.

2.3. Substantiation of choice of base motor vehicle for experimental prototype of electric vehicle

The base motor vehicle referred to here is the conventionally designed vehicle based on the internal combustion engine and converted into an EV on its chassis. Though a propulsion system (propulsion, transmission) is the only thing subject to change in the vehicle. The basic systems of the base vehicle remain unchanged relative to the initial performance and should run normally under the conditions arising from the dismantling of the internal combustion engine.

The car of a popular brand was selected as an alternative option of the base vehicle for the orientation in the applied research and developments. This choice is based on:

- difficulties in terms of technical and functional equipment, on-board electrical equipment, which is capable fullest provide the basis to solve the problems of applied researches, including the adaptation of the standard vehicle staff car systems;
- the possibility of rational distribution of electric drive on-board;
- parameters of standard internal combustion engine, that determine significant opportunity to improve the characteristics of the base vehicle through the use of traction electric drive system;
- presentable exterior, able to garner attention, including of young people, to the results of the development, problems of the environment and the consumption of hydrocarbon fuels.

2.4. Structure and composition of EPS of experimental prototype of EV

In accordance with UN Vehicle Regulation No. 100, the basic functions of electric propulsion system necessary for the implementation in the electric vehicle shall include the production and transformation of:

- mechanical energy for motion of the vehicle;
- electric energy to feed systems ensuring this motion;
- On the basis of the functional characteristics it can generate a generalized structural diagram of the power circuit of electric power system of EV shown in figure 2;
- This EPS structure is implemented in the experimental prototype of EV and it is composed of:
- electric power source (battery, BAT);
- traction motor-generator (TMG);
- traction inverter and TMG control system (TI);
- shutoff protection unit for traction motor (SPU);
- HV power commutation and distribution unit for electric power source (PCDU);
- on-board charging device (OBCD);
- HV air conditioning and heating system (HVAC);

- DC-DC converter for high-voltage battery (DC-DC) and low-voltage power supply for on-board electric equipment;
- auxiliary low-voltage battery (AB);
- vehicle low-voltage electric equipment (LVEE);
- devices for functioning the standard systems of base motor vehicle (DFSS);
- EPS component cooling system (CS);
- control, coordination and monitoring devices for EPS components – high level(main) control system (MCS);
- operational speed controllers of EV (OSC);
- battery management system (BMS);
- Out of scope of the electric propulsion system (EPS):
- mechanical transmission (MT);
- driving wheels (DW).

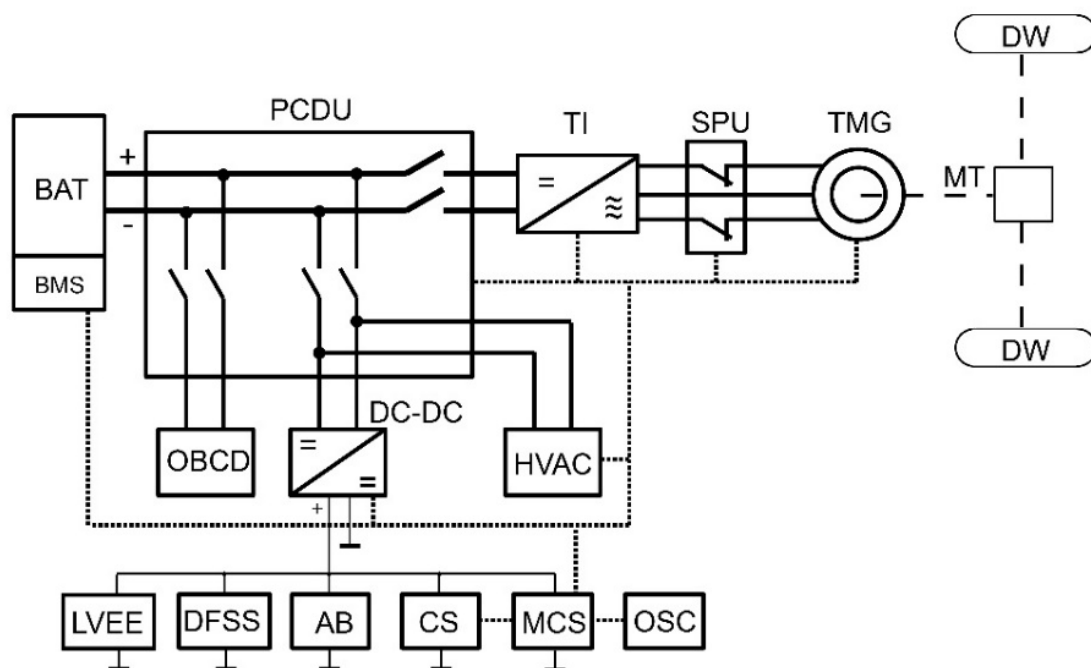


Figure 2. The generalized structural diagram of the power circuit of EPS of EV.

2.5. EPS component layout on experimental prototype of convertible EV

It was highlighted earlier that the particular importance at converting to an electric vehicle shall be given to the rational distribution of the most weight significant components such as traction battery and the electric motor. This task is complicated by the fact that, on the one hand, the weight of traction battery and traction motor shall be distributed on the vehicle, taking into account the allowable mechanical loads on the chassis and body elements, on the other hand, the need to minimize the length of the EPS power and control of electrical circuits. In this paper, the solution of this task was carried out at the expense of battery modular design, consisting of stand-alone functional units – unified battery modules (UBM) and the special design of traction motor.

The layout of EPS components on the base motor vehicle is provided in figure 3 (where MSD - manual service battery disconnect).

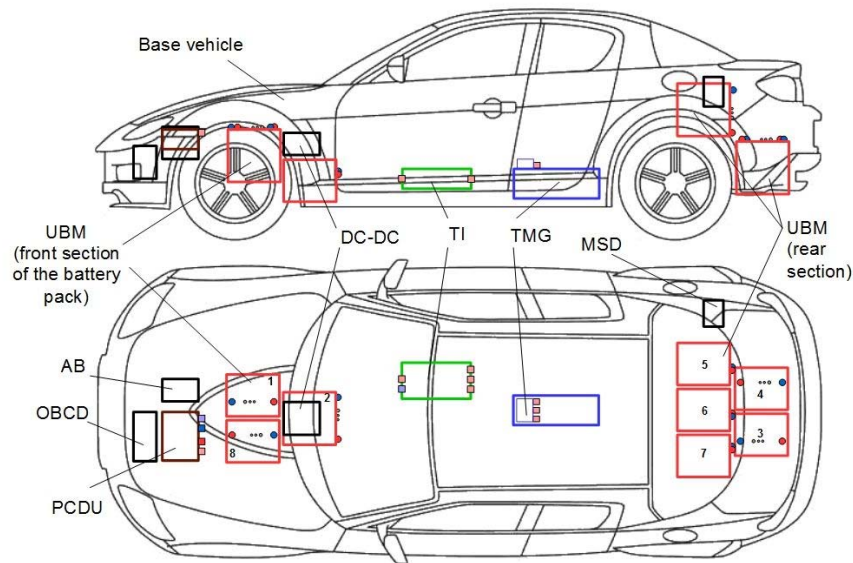


Figure 3. The layout of EPS components on the base motor vehicle.

The design features of base motor vehicle, requirements for placement of equipment required to implement characteristics of electric equipment of EV and the developed basic principles of conversion were crucial while elaborating the EPS key components. The technical description of the key components of developed and manufactured EPS components of experimental prototype of EV is given below.

3. Description of EPS components for experimental prototype of convertible EV

3.1. Traction inverter

The purpose of traction inverter is conversion of voltage as constant for the effective value of the voltage in the adjustable frequency and magnitude of the AC three-phase voltage to control the rotational speed and torque of the traction motor-generator in traction and braking modes.

The main functional features of traction inverter are as follows:

1. The conversion of input DC voltage to three-phase voltage, controlled in magnitude and frequency.
2. The smooth lead-out (in terms of driving comfort of EV) of traction motor to preset current (shaft torque).
3. Automatic maintenance of the preset current (torque) in voltage and power regulation zones of traction motor.
4. Smooth control of torque and rotation speed of traction motor in low power loss mode.
5. Change of the direction of rotation of traction motor.
6. The electric (regenerative) braking the vehicle by translating the traction motor in generator mode with a smooth control of braking torque.
7. Shutoff protection of traction motor in excess of maximum values of force multipliers and input voltage.

3.2. HV power commutation and distribution unit (PCDU)

The purpose of HV power commutation and distribution unit is power commutation in the traction power system and distribution of high voltage between the high voltage devices.

Key functions of PCDU:

1. The remote connection (disabling) of electric propulsion system to electric power source on two terminals (positive and negative).

2. The preliminary battery charge of filter capacitors with limitation of charging current.
3. Automatic disabling of the electric propulsion system from power voltage of electric power source at emergency or abnormal conditions of EPS components.
4. High-voltage distribution of the electric power source between traction inverter, DC-DC converter, HV package switchgear.
5. Integration of devices for monitoring the electrical characteristics of the operating modes of the traction battery and monitoring insulation in EPS.

The PCPU design is shown in figure 4.

3.3. Traction motor-generator

The prospective contactless traction motor-generator is used as a part of the electric propulsion system of the experimental prototype of EV.

Key features of traction motor:

- Type: permanent magnet synchronous motor (PMSM);
- Peak torque: 700 Nm;
- Maximum power on shaft, not less than 140 kW;
- Maximum phase current: 695 A;
- Weight: 97 kg;
- Length: 582 mm;
- Stator diameter, max.: 237 mm;
- Type of cooling: liquid;
- Material of permanent magnets: SmCo;
- Specific power: 1.52 kW/kg;
- Specific torque: 7.22 Nm/kg.

Mechanical characteristic of traction motor is provided in figure 5.



Figure 4. The PCPU design.

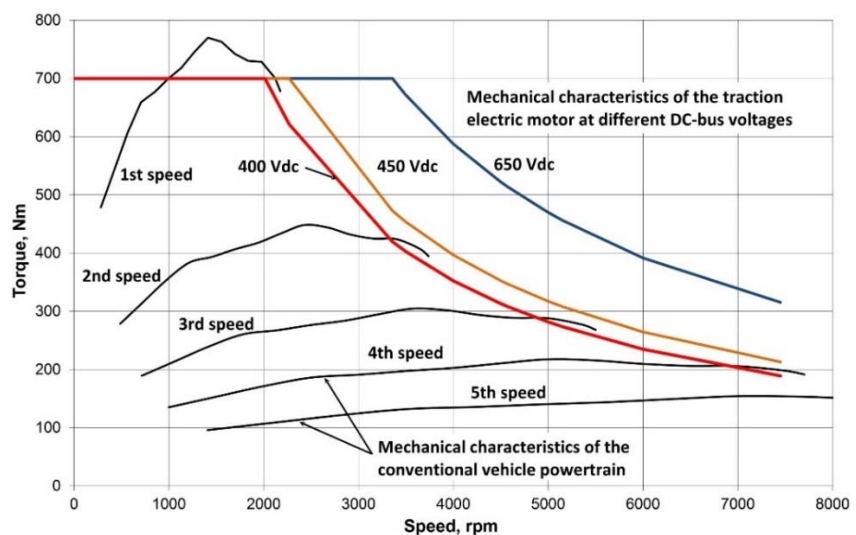


Figure 5. Combined mechanical characteristics of the traction electric motor of EV and convention vehicle powertrain.

The selected technical design of the traction motor is determined by specific feature of conventional design vehicle, which is a central tunnel. The general view of traction motor is shown in figure 6. The used traction motor has a small diameter with an increased length of the active part of the stator. This feature allows a favorable placement of traction motor in the narrow central tunnel of vehicle in close proximity to the differential and drive axle.

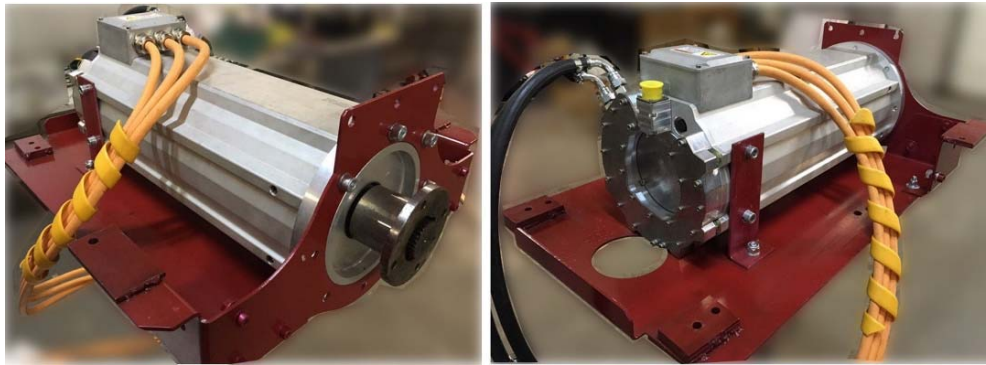


Figure 6. The general view of traction electric motor with mounting.

3.4. Unified battery module

The electric power source is the main on-board power source for motion of an electric vehicle. Key features of unified module of traction battery (UBM):

- Configuration: 12s2p;
- Cells type: Li-ion (NMC+LMO);
- Rated voltage: 45 Vdc;
- Maximum discharge current (10 s): 480 A;
- Maximum charge current: 160 A;
- Rated capacity: 80 A·h;
- Rated energy reserve: 2,6 kW·h;
- Dimensions: 255 x 338 x 316 mm;
- Weight of UBM: 33 kg.

On the basis of unified module of traction battery, it can be built an electric power source of any configuration and preset characteristics.

The characteristics of traction battery pack (TBP) for electric equipment of the electric vehicle:

- Number of connected in-series UBMs: 8 pcs;
- Rated voltage: 360 Vdc;
- Rated energy reserve: 28,8 kW·h;
- Maximum energy reserve: 32,3 kW·h;
- Weight of battery pack: 264 kg.

Technically, UBM is based on the principle of modularity and unification to generate on the basis of a functional and complete stand-alone unit of the electric power source of the preset configuration and characteristics.

Structurally, the UBM consists of composite plastic elements-frames that generate an UBM housing (see figure 7).

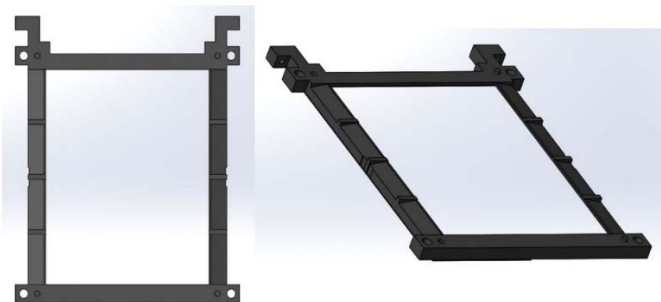


Figure 7. The composite plastic frame of UBM.

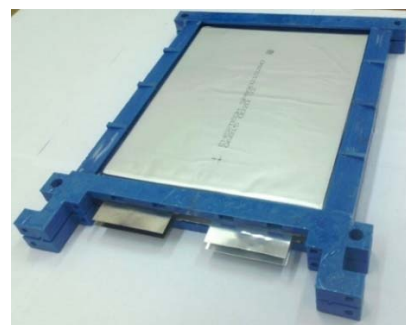


Figure 8. The UBM assembly section.

One UBM section consisting of two frames encloses two prismatic battery cells (see figure 8). The frame design determines the following functions:

- building-up the composite protective housing;
- fixation of battery cells in module;
- access for heat sink from battery cell.

The UBM sections are combined together using the tightening pins into a single structure, protected by aluminum plates on the edges.

The electrical connection of the battery electrodes is carried out in a special compartment formed by the configuration of the plastic frame. The same compartment encloses battery status control devices (BMS board) and is provided to connect the power cables to the power terminals of the UBM.

The heat sink of each battery in module is done through special air ducts, formed by a plastic frame. If necessary, forced air circulation can be arranged through air ducts using cooling fans fitted on the UBM or nozzles laid down from the external cooling system. The design of the UBM is shown in figures 9 and 10.

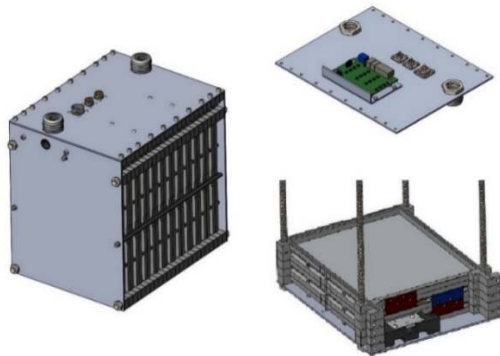


Figure 9. The concept of UBM.



Figure 10. Traction battery modules of Convertible EV.

3.5. Mechanical transmission components of EV

The design of the mechanical transmission assemblies provides:

- minimization of weight and dimensions of traction electric drive;
- minimization of mechanical losses in the transmission of torque;
- lack of intermediate devices of torque conversion and rotation speed (gears, gearbox);
- design reliability and relative ease of manufacture at a maximum preservation of standard units and aggregates of the base motor vehicle.

The general view of traction electric drive for electric equipment of the electric vehicle is provided in figure 11.

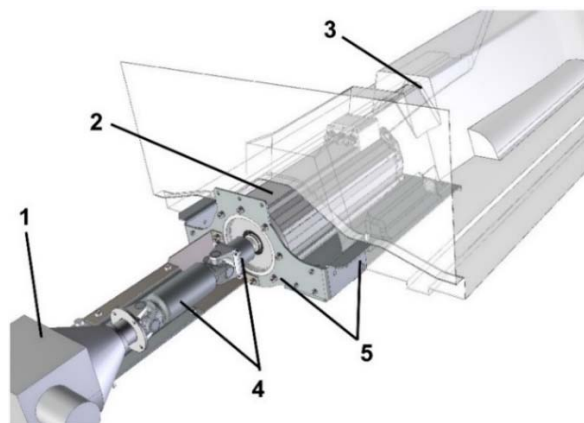


Figure 11. The general view of traction electric drive for electric equipment of EV.

There are shown: 1 is main gear (differential) of the base motor vehicle; 2 is traction motor-generator; 3 is central tunnel of base motor vehicle; 4 is mechanical transmission elements; 5 is structural elements to install electric equipment.

4. Conclusions

The practical implementation of the developed full technological cycle concept for conversion of conventional vehicles to EVs is based on the solution of a set of particular tasks concerning optimization of EPS structure, type, and characteristics of its constituent components, as well as the characteristics of their design and placement in the vehicle.

An idea of conversion is not new, however, today's existing concepts and technical solutions eliminate the creation of truly effective solutions in relation to consumer and operational properties of an electric vehicle. The latter is possible only by following the specific criteria and principles, among which it is especially worthwhile to highlight the principle of conservation of traction and dynamic performance and functions of standard on-board systems of the base motor vehicle. The modern electric vehicle of today shall be distinguished by:

- use of AC traction motors-generators (squirrel-cage motors or permanent magnet synchronous motors);
- use as a component of the traction battery of battery cells based on lithium-ion technology with values of specific energy of at least 140 Wh/kg;
- modular design of the electric power source;
- use of advanced methods of algorithms [2] to control electric machines as well as liquid cooling in converted electrical equipment;
- lack of speed-change gearbox;
- lack of cabin heaters operating on hydrocarbon fuels or based on traditional thermoelectric power resistive heaters.

The above features distinguish this developed concept of a full technological cycle for conversion of conventional internal combustion vehicles to electric vehicles and the presented results of the practical implementation of this concept.

The results in the presented work can be applied to both passenger vehicles and special municipal vehicles and buses and present a reality in which it is feasible to upgrade the existing motor transport systems currently in use in public transportation.

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