RESEARCHES ON POWER TRANSMISSION SYSTEMS OF TRACTION VEHICLES WITH A HYBRID DRIVE

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Abstract

The structures of modern traction vehicles are based on new generation devices. Technical progress within the field of power transmission concerns such elements as sources of power supply, electric devices and energy electronic solutions in power transmission systems. The prototypes of traction vehicles being currently drawn up are hybrid vehicles using different kinds of sources of power supply of power transmission systems, the most important of which are combustion engines, contact systems, supercapacitors (ultracapacitors), accumulators and fuel cells. Main engines are usually electric machines. In energy electronic starting systems it is permissible to use all kinds of main electric engines, for example, direct-current motors (inline engines, commutator motors with permanent magnets or non-commutator motors) or three-phase motors of alternating current (induction and synchronous). This means a complete change of rules in energy managing in a vehicle. Sources of energy can have the function of basic power supply (contact system, combustion engine or combustion cell) or the function of power supply support (supercapacitors, accumulators or fuel cell). New functions of drive operation will be available, namely, leveling of basic power supply load, recuperation of braking energy of the whole train set, driving at the temporary disconnection of basic power supply (short-term application of accumulator as basic power supply). Each of the above functions can contribute to the improvement of watt-hour efficiency of the system or to prolonging the range of driving. Therefore, it is necessary to undertake research on new generation power transmission systems. Research tasks focus on measurement of state variables of a drive, analyses of traction signals, modeling of drive operation in the conditions of driving cycle realization, verification of a model, drawing up a strategy of energy management in order to achieve the best watt-hour efficiency and the range of driving. In the article presented, sample results of researches on applications of hybrid power transmission systems conducted in various national research centers will be demonstrated. They concern both theoretical research (model simulation) and prototype research. The conception will be presented of a laboratory station for conducting research on modern sources of power supply and drives, which is currently being built at the Faculty of Transport of Warsaw Polytechnic at the Division of Exploitation of Tracking Systems and Electric Equipment in Transport.

Keywords *transport, hybrid drive vehicles, unconventional power supply sources, electric machines, energy accumulators -super capacitors*

1. Introduction

Recent price rises of liquid fuel have forced constructors of means of transport to search for new solutions concerning vehicle driving systems. This trend refers both to motor transport, in which the function of the main drive is at present performed mainly by combustion engines, and track transport, in which the use of electric engines prevails. Technological progress in the field of energy sources construction makes it possible to use new sources of basic power supply (e.g. fuel cells) as well as new sources of auxiliary power supply (the so called accumulators). Application of these technologies in means of transport resulted in creation of the so called hybrid drive systems comprising more than one kind of energy source (where usually one of the drives constitutes a combustion engine). The system creates new possibilities of energy supply to drive wheels, which favors liquid fuel economy such as decreasing participation of combustion engine in basic power supply, or streamlining energy use needed for motion due to the use of accumulators. Limiting traction energy use needed for motion (in relation to classic solutions) results from the possibility of recuperation of kinetic energy of a braking vehicle. Generally speaking, the functions of accumulator can be presented in the following way: recuperation of braking energy to accumulator, load compensation of basic power supply source, short-term work with disconnected basic power supply (short-term accumulator use for the main drive).

As it follows from the researches, the use of fuel cells in means of transport encounters problems connected with energy-consumption of acquisition and distribution of hydrogen [12]. Much easier is the use of energy accumulators. At present, the use is being considered of different kinds of accumulators such as electrochemical accumulators, pellet energy accumulators or supercapacitors. [8]. Electrochemical accumulators are characterized by the highest energy density. Their basic fault is limited life (about 1000 working cycles) with power overload constraints. In this case supercapacitors obtain better working parameters. However, they must be joined into stacks, which increases leakance of systems and limits time possibilities of energy storage. It seems that a relatively good technical solution is the construction of supercapacitor-accumulator placed on a vehicle as an auxiliary power supply source. This type of solution for driving systems with auxiliary energy supply can be used independently of traction type (track or wheel) and also of the manner of basic energy supply: network traction (e.g. trolleybus) or autonomic (e.g. diesel-electric locomotives as well as motor vehicles).

At the present moment, the first cars with hybrid diesel-electric drive are offered, which are equipped with electric energy accumulators [4], and also the first diesel-electric locomotives with a battery accumulator [10]. Application of hybrid systems in public transport including track transport is more difficult because of higher driving power. Studies and researches on the possibilities of implementation of hybrid drive systems in track transport have been conducted in the most important foreign centers [1, 2] as well as in Poland, in such centers as Silesian Polytechnic [5] and Warsaw Polytechnic [6, 7, 9]. The first national studies concerned modernization applications. Among theoretical studies (not concluded with a stage of prototype construction) there is for example a study of assumptions for modernization of diesel-electric locomotive SP 42 [6, 7]. Among studies concluded with prototype construction and prototype research, above all there are studies conducted in Electrical Engineering Institute concerning the construction of a tram with a battery accumulator for the city of Warsaw [9] and a trolleybus with a supercapacitor accumulator for the city of Lublin [3]. Transport Faculty of Warsaw Polytechnic has started the first stage of construction of multi-function laboratory station for research on power supply sources and driving systems of traction vehicles [3]. The second stage of this laboratory station construction anticipates the use of a combustion cell. At the same time, Electric Faculty of Warsaw Polytechnic and Automatics Faculty of AGH are conducting research on the use of pellet energy accumulators placed in power supply systems of railway substations. This type of substation is characterized by the highest possible speed of access to accumulated energy.

2. Researches on operational efficiency of a tram with a battery accumulator

The purpose of application of an energy accumulator in a tram is to create the possibility of short-term work without network or unconditional recuperation of energy. In trams supplied by network only, the condition for proper recuperation course is energy supply to another vehicle (receiver) being within the same power supply section. The attempt at realization of recuperation without the possibility of energy reception from another vehicle is concluded with disconnecting the system from network. Further electric braking can be conducted only in the mode of resistor braking. In practice, because of relatively high short-term fluctuations of tram network voltage values, realization of proper recuperation courses is troublesome. In this case application of energy accumulator will cause improvement of energy indicator values of vehicle operation.

A prototype tram driving system with a battery accumulator has been created in Electrical Engineering Institute. Sample results of measurement and registration of the following signals: supply current (i_z), group of engines current (i_g), battery accumulator voltage (u_c) and speed (V) have been presented in Fig. 1. Obtained mechanical and electric power functions have been presented in Fig. 2. Function graph of driving operational efficiency has been presented in Fig. 3 [9].

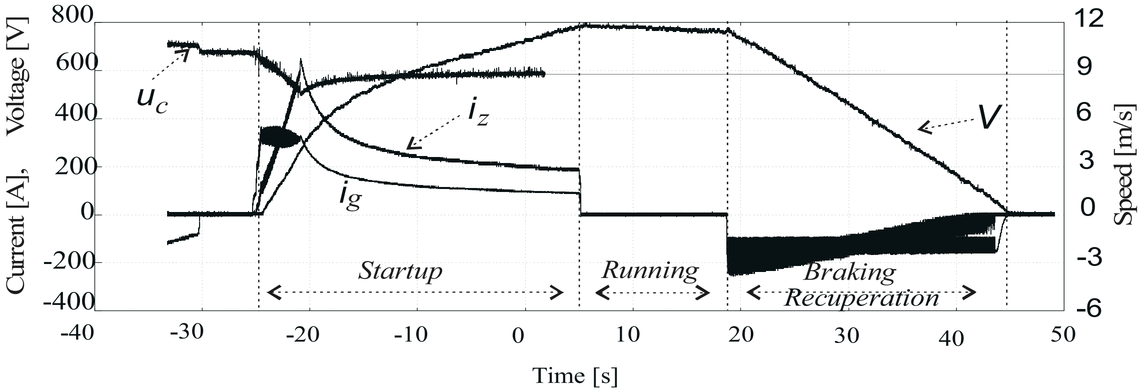

Fig. 1. Measurement signals of vehicle supply current, i_g - current of one group of traction engines, V - speed function, u_c - battery voltage

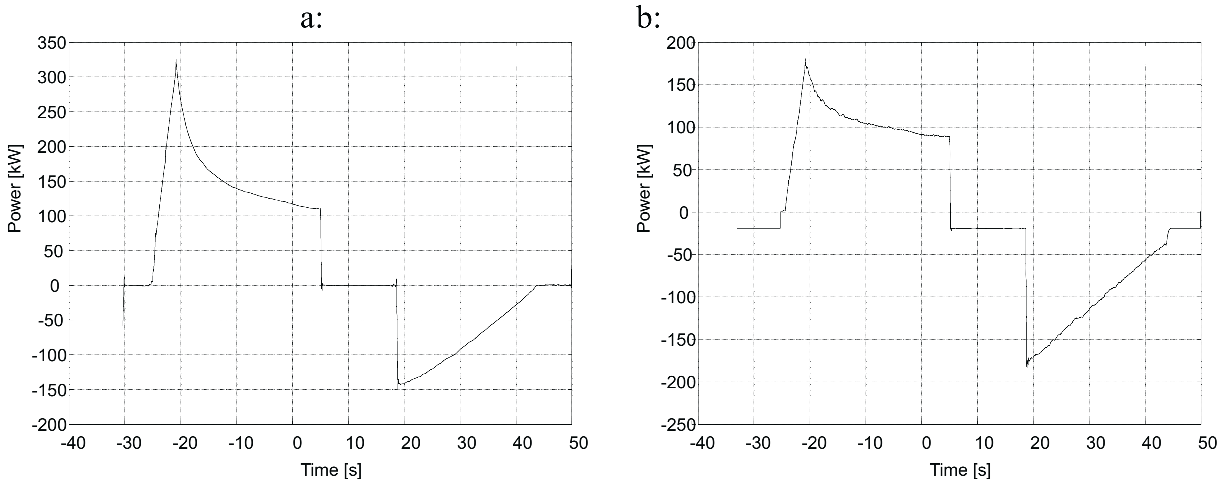

Fig. 2. System powers: a) input, b) output

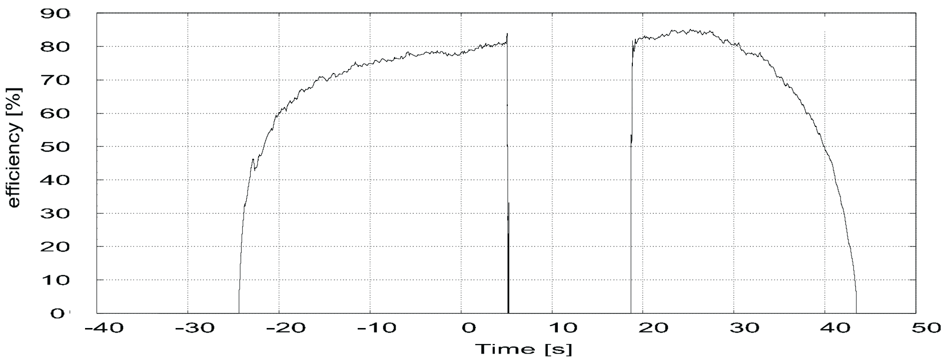

Fig. 3. Function graph of electric operational efficiency determined on the basis of measurement results and calculations with the use of circuital engine model

Calculated amounts of driving cycle energy are running in the following way [9]: energy taken from the source during startup W_{1R} = 4.5620 MJ (1.2672 kWh), recuperation energy returned to the source W_{1H} = -2.0327 MJ (-0.56463 kWh). Therefore, percentage recuperation energy return in relation to startup energy equals 2.0327/4.5620*100 = 44.557%. It is evident that the use of energy accumulator increases efficiency of energy economy by half. However, it should be indicated that percentage results of energy saving are strongly dependent on the realized motion conditions. The result presented above refers to a short road section between the stops. When driving on long distances, the amount of energy taken from the source increases, whereas recuperation energy amounts are approximately constant (at similar speed at the beginning of braking). Efficiency of energy saving decreases with the increase of distance between the stops. In practice, in public transport traffic due to the use of energy accumulator, relative energy saving can be anticipated at the level of 15-20%.

3. Laboratory station for testing modern power supply sources and vehicle driving systems

At the present moment, in the Division of Exploitation of Tracking Systems and Electric Equipment in Transport at the Faculty of Transport of Warsaw Polytechnic, construction of a laboratory station for testing modern power supply sources and vehicle driving systems is being designed. Ideological diagram of the station has been presented in fig. 4. At the station, researches will be conducted on energy economy strategies in hybrid driving systems in working conditions reproducing operational cycles of electro-traction devices.

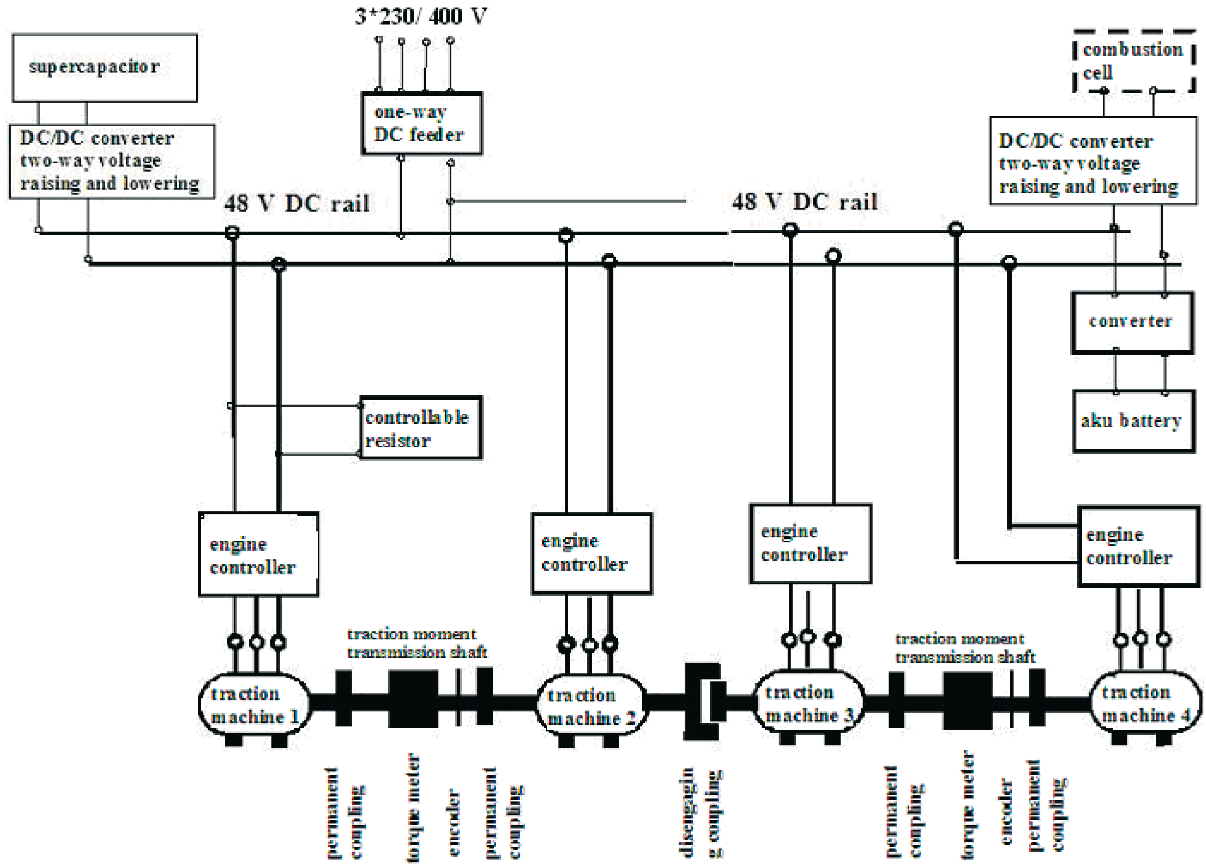

Fig. 4 Ideological block diagram of the station

The station lacks the weight of a vehicle moving linearly. Reproduction of the motion of a vehicle wheel set of a given weight requires the use of a control system equipped with computational model for indicating substitute value speed functions, driving power and wheel set load. Examples of signals of process driving characteristics reproducing vehicle working cycle for the following motion stages: startup, running, braking have been presented in figures: 4 - traction characteristics, 5 - speed function, 6 - driving power, 7 - load power of wheel set shaft.

It is anticipated that basic technical parameters of the system will have a connection with the exploited or implemented into operation (as prototypes) hybrid driving systems of vehicles.

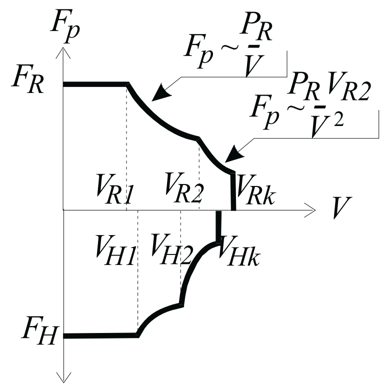

Fig. 5 Sample traction characteristics of the drive for one-way work

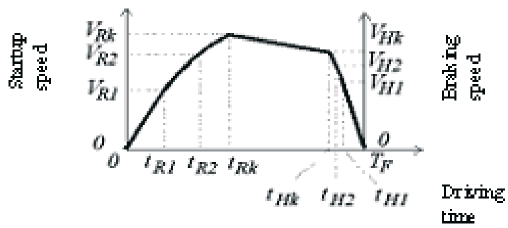

Fig. 6 Sample vehicle speed function

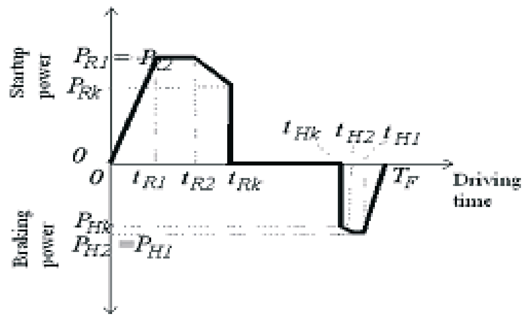

Fig. 7 Sample driving power function

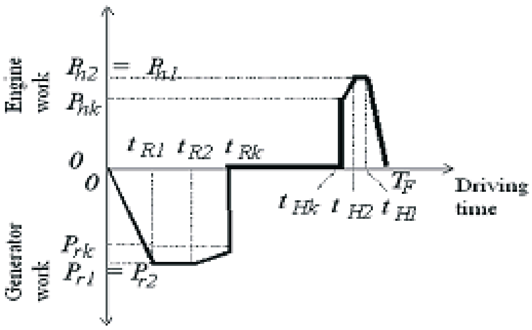

Fig. 8 Sample shaft load function

In relation to the above, the following requirements have been established: power supply from integrating network 48 V DC, minimal engine power 4 kW, maximum rotation speed at the voltage of 48 V 1500 rpm, minimal weight of a reproduced vehicle 500 kg, minimal reproduced driving speed 15 m/s. Anticipated startup time up to the maximum speed with the use of continuous engine power - 60 s, with the overload of 150% - 40 s. Permissible short-term startup current overload - 250% - 10 s. Driving cycles' times with the use of continuous power - up to 4 min, with power overload of 150% - up to 1.5 min. Maximum value of accumulator energy transfer not exceeding maximum kinetic energy value of a braking vehicle (100 kJ). In the first stage of construction, it is planned to connect the following: DC feeder, battery block of the capacity of 180 Ah with the voltage of 60 V and supercapacitor block of the capacity of 94 F with the voltage of 75 V. In the second stage - a fuel cell of the power of 1.2 kW (in fig. 4 indicated by a dotted line).

Measuring system of signal registration and analysis for multifunctional station encompasses 24 channels (2 digital, 22 analogue). Measurements of electric values are realized by means of LEM type converters of the following minimal measurement range values: current up to 300 A, voltage up to 100 V. Mechanical values detectors: two extensometric torque meters and two digital encoders. Extension of the system is anticipated of additional measuring channels. Total minimal number of analogue channels equals 32. Signal registration and controlling a chosen research programme is conducted by means of a computer equipped with appropriate measuring cards.

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