

**Power supply method for a railway vehicle, related in-station supply system,
onboard energy storage system, and related railway vehicle**

The present invention relates to a power supply method for a railway vehicle including an onboard energy storage system.

5 In general, electric public transportation vehicles are supplied with electricity using electric contacts between the vehicle and its feeder rail via a shoe, or between the vehicle and its catenary via a pantograph, supplying the vehicles with outside power.

Vehicles are also adapted to travel over at least a portion of the journey in an independent power supply mode using an onboard energy storage system, without
10 requiring an outside power supply source, and therefore without requiring permanent electric contacts between the vehicle and its capture rail or catenary.

This operation in independent power supply mode makes it possible to respect certain esthetic constraints (preservation of the landscape, for example near protected monuments, etc.) or technical constraints (e.g. in the event overhead cables are
15 prohibited, to allow exceptional convoys to pass, etc.).

Such an onboard power supply system includes an energy storage module (for example with ultracapacitors and/or a flywheel and/or a battery, etc.) and a direct-direct voltage converter (chopper) that makes it possible to adapt the characteristics of the supplied charge or discharge electrical energy to the constraints of said storage module.

20 The onboard power supply system enables the reception, adaptation, and storage strictly speaking of the electrical energy so as to electrically power the various pieces of equipment onboard the railway vehicle in independent power supply mode.

Charging of the storage module via the chopper can be done by recovering braking energy, the energy previously supplied by traveling in external power supply mode
25 from the electric contacts of the pantograph or the shoes, or when the vehicle is stopped in the station.

Document EP 1765631 describes such a power supply device comprising an energy storage system including one or more flywheels, one or more power batteries, and one or more ultracapacitor assemblies.

30 Generally, the charge done beforehand (for example by rapid recharge when stopped in a station) allows the vehicle to perform only an "easy" station spacing, i.e. fairly short on a profile with a relatively small slope, in independent mode (i.e. the path between two stations). This is due to the charging time, which may not exceed the passenger exchange time. The onboard chopper is used today to charge the storage module both
35 while at the station and in motion.

This onboard chopper is dimensioned to recover the braking energy while in motion, but it would also be of interest, when the commercially available energy storage capacities increase (which is in the process of happening), to be able to charge it while stopped, in an amount of time compatible with the passenger exchange time, with greater energy making it possible to travel longer spaces between stations or spaces between stations with more significant level differences, or to power the auxiliaries during extended stops between two stations. However, the onboard chopper does not make it possible to handle very significant transferred powers, which limits the recharged energy in compliance with the authorized stop time at the station.

Furthermore, major constraints weigh on the size of the onboard power supply system. In fact, the vehicle having to be accessible in particular to people with reduced mobility and strollers, the elements of the power supply system must be positioned on the roof of the vehicle, occupy as little space as possible, and have a reasonable mass. The significant stopped recharges mentioned above would then require oversized choppers for the energy recovery function while in motion and would no longer be able to be housed on the rolling stock.

To that end, according to a first aspect, the invention relates to a power supply method of the aforementioned type, characterized in that:

- a stationary static energy converter, located at a stop station of the vehicle, receives the electric energy;
- the railway vehicle being stopped at the station, a transfer of energy to the onboard energy storage system is done by the stationary static converter from said received electrical energy, said stationary static converter adapting the voltage supplied to the onboard energy storage system as a function of the status of the charge of said onboard energy storage system;
- the onboard energy storage system is charged as a function of the energy transferred under the voltage adapted by the stationary static converter.

Such a power supply method makes it possible to electrically recharge the vehicle at the station using a chopper sized to then allow independent operation on:

- a track section between two adjacent stations having difficult characteristics (length and slope),
- a track section between stations made difficult by a prolonged stop on the line,
- over several track sections between two adjacent stations.

The charge must always be done in a very short period of time (about 20 seconds), corresponding to the time for passengers to enter and exit the train at the station.

In fact, the chopper in an onboard independent system today can transfer approximately 300 kW of energy instead of approximately 750 kW, making the difficult track sections between adjacent stations defined above impossible, and which the invention allows. Given the aforementioned constraints on the size of the railway vehicle, it is not possible to consider having an onboard chopper of more than 500 kW.

In particular embodiments, the power supply method according to the invention also comprises one or more of the following features:

- the onboard energy storage system includes an onboard static energy converter and an energy storage module, the onboard static energy converter being adapted to transfer energy to the energy storage module by adapting the voltage supplied to the energy storage module as a function of the charge state of said energy storage module, wherein the stationary static energy converter and the onboard static energy converter cooperate during an energy transfer by the stationary static converter to the onboard energy storage system;

- during an energy transfer by the stationary static converter to the onboard energy storage system, the onboard static energy converter monitors the state of the energy storage module, and steers the operation of the stationary static converter as a function of said monitored state;

- the stationary static converter has a transferred power characteristic of a value between 500 and 3000 kW;

- the onboard static energy converter has a transferred power characteristic of a value between 300 and 500 kW;

- the stationary static converter and the onboard static energy converter include choppers, and according to which the energy storage module includes ultracapacitors.

According to a second aspect, the invention relates to an in-station power supply system intended to power a railway vehicle including an onboard energy storage system, said in-station power supply system including a stationary static energy converter, located at a stop station of the vehicle, adapted to receive electrical energy and to transfer said energy to the onboard energy storage system when the railway vehicle is stopped in said station, said stationary static converter adapting the voltage supplied to the onboard energy storage system as a function of the charge state of said onboard energy storage system.

According to a third aspect, the invention relates to an onboard energy storage system of a railway vehicle, including an onboard static energy converter and an energy storage module, the onboard static energy converter being adapted to transfer energy to the energy storage module by adapting the voltage supplied to the energy storage module

as a function of the charge state of said energy storage module, in which the onboard static energy converter is adapted to cooperate with a stationary static energy converter located at a stop station of the vehicle, during an energy transfer done by the stationary static converter to the onboard energy storage module, the onboard energy storage system being charged as a function of the energy transferred at voltage adapted by the stationary static converter.

According to a fourth aspect, the invention relates to a railway vehicle including an onboard energy storage system according to the third aspect of the invention.

The invention will be better understood upon reading the following description and in light of the accompanying figure. This figure is provided for information, but is in no way limiting on the invention. These figures are as follows:

- figure 1 is a diagrammatic view of a public transportation vehicle in one embodiment of the invention.

Figure 1 diagrammatically illustrates a vehicle 1 in one embodiment of the invention, for example a tramway.

This tramway 1 is intended to carry passengers. Vehicles incorporating the invention may be non-railway vehicles (buses, trolleys, etc.) or may be designed to carry goods, etc.

The tramway 1 comprises:

- pulling elements in particular comprising at least one electric motor 4 adapted to generate a pulling torque driving wheels 6 of the tramway, when said pulling elements are supplied with electric energy;
- an onboard power supply system 7;
- auxiliary equipment, not shown, such as air conditioning, lighting, heating, door opening/closing management equipment, etc., not participating in pulling the vehicle.

The onboard power supply system 7 comprises electrical energy storage means 2. In the present case, this storage means includes an ultracapacitor module connected in series or parallel, which will hereafter be designated by reference 2.

The onboard power supply system 7 also comprises an onboard static energy converter 3, which includes a chopper "Hemb" in the considered case, which will hereafter be designated by reference 3. In the considered case, the chopper "Hemb" 3 is reversible (i.e. the energy can pass through in both directions).

Due to the bulk constraints of the tramways, the static converter 3 and the ultracapacitor module 2 are positioned on the roof of the tramway 1.

As an illustration, the characteristics of the ultracapacitor module 2 are, in terms of transferred energy, from 4 to 20 kWh, and in terms of transfer power, from 500 to 3000 kW.

As an illustration, the characteristics of the chopper 3 are, in terms of transferred energy, from 300 to 500 kW and with a size of about 1.5 cubic meter.

As a reminder, an ultracapacitor is an electrostatic component for storing electric charges, formed by creating a double electrochemical layer. It comprises two conductive electrodes containing activated carbon, separated by an ion solution (electrolyte). Electrical charges accumulate at the interface between the ion solution and the electrode. The charges/discharges of the ultracapacitors are relative to the movement of the ions between substrate layers having different polarities. The interface between the charges acts as a dielectric. The stored energy is the result of a capacitive effect. No oxidation-reduction reaction occurs.

The charge or discharge voltage at the terminals of the ultracapacitor module is a direct voltage, which can vary greatly depending on the charge state of the ultracapacitors, for example between 400 V and 800 V (the energy contained in the ultracapacitor system is a function of the square of the voltage at the terminals of the ultracapacitor module).

The tramway 1 comprises a switching device 5 "Semb" adapted so as, when the tramway 1 is in the independent power supply mode, to supply the pulling elements 4 and auxiliary equipment with the energy contained in the onboard power supply system 7.

The switching device 5 "Semb" is also adapted so as, when the tramway 1 is powered while in motion by an external source via a pantograph or a contact on the ground, to provide the pulling elements 4 and auxiliary equipment, and potentially the onboard power supply system 7, with the energy from the external source.

The switching device 5 "Semb" also makes it possible, when the tramway 1 brakes, to supply all or some of the recovered braking energy to the onboard storage system 7 and/or to supply all or some of the recovered braking energy to the external electric network, via a pantograph or a contact on the ground.

The operation of the tramway during the movement thereof between stations is first described below, in outside power supply mode, then in independent mode.

Secondly described is the operation of the tramway when it is stopped at a station.

First part:

The tramway 1 moves along guide rails. In sections of its journey, the tramway 1 moves while being connected to an external power source, which provides a direct voltage with a substantially fixed value (for example 750 V). It captures that energy for

example using a pantograph cooperating with a catenary or by a feeder rail positioned on the ground (not shown).

This energy is received by the switching device 5 "Semb" that supplies it, in whole or in part, to the motor 4 and to other pieces of equipment of the tramway consuming energy.

In one embodiment, part of this energy is supplied to the onboard storage system 7, in the form of a direct voltage V1, for example 750 V.

The onboard chopper 3 "Hemb" receives said voltage V1, adapts it as a function of the charge state of the ultracapacitor module 2, then supplies a direct voltage V2 thus adapted to charge the ultracapacitor module 2. The adaptation is continued throughout the charge.

The electric motor 4 is reversible and adapted to generate, during braking, a braking torque supplying electricity. The tramway 1 is adapted in the considered case so as, during a braking operation of the tramway 1, to recover the braking energy supplied by the motor 4 and to transmit it, via the switching device 5, either in part or in whole, to the outside network by means of the catenary (potentially to power another tramway or an outside storage element) and/or to the power supply system 7 to recharge the ultracapacitor module 2, in the same way as previously described.

Furthermore, in one or more other sections of its journey, the tramway 1 is not connected to any external electrical power supply source.

The tramway is then supplied with electricity only by the onboard storage system 7, in a so-called independent electrical power supply mode.

In this independent power supply mode, the ultracapacitor module 2 is discharged and supplies a direct electric voltage V2 to the chopper "Hemb 3". The voltage V2 being variable as a function of the charge state of the ultracapacitor module 2, the chopper "Hemb" 3 adapts that voltage received as input, and supplies the switching device 5 "Semb" with a direct voltage V1 suitable for equipment alongside the tramway 1 requiring an electricity supply, including the pulling motor 4 and the auxiliary equipment.

When the tramway brakes on a journey in independent power supply mode, the braking energy can be supplied to the onboard storage system 7 for a recharge as previously described.

Second part:

The tramway 1 is also adapted to stop in predetermined geographical locations, called stations, to allow travelers to enter and/or exit the train. The duration of these stops is generally between 20 and 40 seconds, for example 20 seconds in the considered case.

Figure 1 shows a station 10 in one embodiment of the invention.

In this station 10, there is a stationary power supply system 13, including a chopper 11 connected to an Sstat energy source 12, which is for example the stationary electric network supplying a direct voltage of 750 V.

The chopper 11 is adapted to transfer, when the tramway is stopped at a station, enough electrical energy to partially or completely charge the electricity storage means 2.

In the considered case, the static converter 11 includes a chopper "Hstat", which will hereafter be designated by reference 11.

As an illustration, the characteristics of the chopper "Hstat" 11 are for example: 500 to 3000 kW in terms of transferred power, and it occupies a volume of 2 to 5 cubic meters.

In the considered case, the chopper "Hstat" 11 is positioned on the ground, under the parking area of the tramway when it is stopped. A means for providing an electrical connection between the chopper "Hstat" 11 and the tramway 1 is positioned at the ground and once activated, for example when the presence of the tramway 1 is detected, makes it possible to electrically connect the chopper "Hstat" 11 and the onboard ultracapacitor module 2.

Thus, once the tramway 1 is stopped in the station 10 and this electrical connection is activated between "Hstat" 11 and the ultracapacitor module 2, the transfer of energy can begin: the source 12 supplies energy corresponding to the electrical voltage "Vstat" to the chopper "Hstat" 11, which adapts that voltage, as a function of the charge state of the ultracapacitor module 2, and delivers a direct voltage V3 thus adapted to the ultracapacitor module 2 to charge it. The adaptation is continued throughout the charge.

Furthermore, in one embodiment, the onboard chopper "Hemb" 3 is adapted to monitor the state of the ultracapacitor module 2 during this charge at the station and to exchange information with the Hstat 11. In one embodiment, it detects malfunctions, for example overheating and/or defective charge phenomena. It may detect the charge state of the ultracapacitor module 2 of the onboard storage system 7. In one embodiment, the voltage adaptation by the Hstat 11 is reviewed as a function of the data supplied by the Hemb chopper 3 and representative of the state thus detected by the chopper "Hemb" 3.

In one embodiment, the chopper "Hemb" 3 is adapted to command the chopper "Hstat" 11 at the station to stop the charge, for example when a malfunction is detected and/or when the ultracapacitor module 2 is completely charged.

In another embodiment, the placement of the chopper "Hstat" 11 and the ultracapacitor module 2 in electrical contact for example occurs using a pantograph or any other means.

In another embodiment, the chopper is not underground, but positioned in an equipment room on the ground, or in any other configuration.

Thus, the "Hstat" chopper 11 in station is suitable for a charge comprised in a power range of 500 to 3000 kW, for example 750 kW in the case at hand. It thus makes it possible to completely recharge the ultracapacitor module 2 during the limited length of the stop, for example 20 seconds.

The onboard chopper "Hemb" 3, with dimensions suitable for the bulk allowed in the tramway, makes it possible to adapt the voltage for the ultracapacitor module 2, outside charges done at the station 10 or at similar stations, to prepare a track section between two adjacent stations in independent mode in motion. It is suitable for a charge in a power range of 200 to 500 kW, for example 300 kW in the case at hand, which is sufficient for the charging of the ultracapacitor module done during braking or while in motion. In one embodiment, it performs functions to monitor the status of the ultracapacitor module 2 and steer charging, both during charging of the ultracapacitor module 2 done using a voltage transferred and adapted by the "Hemb" chopper 3 itself, and during charging of the ultracapacitor module 2 done using a voltage transferred and adapted by the "Hstat" chopper 11 at the station. Such an arrangement makes it possible to pool these control means and simplify the configuration of the chopper at the station.

The invention has been described above considering that the static converters 3 and 11 would include choppers, adapted to allow charging of an ultracapacitor module 2.

In another embodiment, the energy storage system includes (in place of or in addition to the ultracapacitor module) an electrochemical battery and the static converters 3 and 11 include voltage converters designed to adapt the "Semb" and "Sstat" electricity sources to the battery. In one embodiment, the static converter 3 also being adapted to adapt, in the independent power supply mode, the energy supplied by the battery to the constraints of the motor.

In another embodiment, the energy storage system includes (in place of or in addition to the ultracapacitor module and/or the battery) a flywheel and the static converters 3 and 11 include voltage converters designed to adapt the "Semb" and "Sstat" electricity sources to the flywheel (conversion of the direct current into alternating current). In one embodiment, the static converter 3 also being adapted to adapt, in the independent power supply mode, the energy supplied by the flywheel to the constraints of the motor (conversion of the alternating current into direct current).

In one embodiment, the stationary static converter, for example the chopper, is reversible and is adapted to receive the energy supplied by the onboard energy storage system in the vehicle.

This arrangement is particularly useful in the case where the onboard energy storage system has accumulated too great a quantity of energy to be able to recover energy again from the following track section between adjacent stations, for example after steep descents. This energy transferred by the chopper coming from the onboard energy storage system is then for example supplied to the direct external network via a reversible substation or stored in a suitable system on the ground.

CLAIMS

- 5 1. A power supply method for a railway vehicle (1) including an onboard energy storage system (7), characterized in that:
- a stationary static energy converter (11), located at a stop station (10) of the vehicle, receives the electric energy;
 - the railway vehicle being stopped at the station, a transfer of energy to the
10 onboard energy storage system (7) is done by the stationary static converter (11) from said received electrical energy, said stationary static converter adapting the voltage (V3) supplied to the onboard energy storage system as a function of the status of the charge of said onboard energy storage system;
 - the onboard energy storage system (7) is charged as a function of the energy
15 transferred under the voltage (V3) adapted by the stationary static converter.
2. The power supply method according to claim 1, wherein the onboard energy storage system (7) includes an onboard static energy converter (3) and an energy storage module (2),
20 the onboard static energy converter (3) being adapted to transfer energy to the energy storage module (2) by adapting the voltage (V2) supplied to the energy storage module as a function of the charge state of said energy storage module, wherein the stationary static energy converter (11) and the onboard static energy converter (3) cooperate during an energy transfer by the stationary static converter to
25 the onboard energy storage system.
3. The power supply method according to claim 1 or 2, wherein, during an energy transfer by the stationary static converter (11) to the onboard energy storage system (7), the onboard static energy converter monitors the state of the energy storage
30 module, and steers the operation of the stationary static converter as a function of said monitored state.
4. The power supply method according to any one of the preceding claims, wherein:
- the stationary static converter (11) has a transferred power characteristic of a
35 value between 500 and 3000 kW;

- the onboard static energy converter (3) has a transferred power characteristic of a value between 300 and 500 kW.

- 5 5. The power supply method according to any one of the preceding claims, wherein the stationary static converter (11) and the onboard static energy converter (3) include choppers, and according to which the energy storage module includes ultracapacitors.
- 10 6. An in-station power supply system (13) intended to power a railway vehicle (1) including an onboard energy storage system (7), said in-station power supply system including a stationary static energy converter (11), located at a stop station of the vehicle, adapted to receive electrical energy and to transfer said energy to the onboard energy storage system (7) when the railway vehicle is stopped in said station, said stationary static converter (11) adapting the voltage (V3) supplied to the onboard energy storage system (7) as a function of the charge state of said onboard energy storage system.
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- 20 7. The in-station power supply system (13) according to claim 6, wherein the stationary static converter (11) is adapted to cooperate, during said transfer, with an onboard static energy converter (3) of the onboard energy storage system in the vehicle, said onboard static energy converter being intended to transfer energy to an energy storage module (2) of the onboard energy storage system (7) by adapting the voltage (V2) supplied to the energy storage module as a function of the charge state of said energy storage module.
- 25 8. The in-station power supply system (13) according to claim 6 or 7, wherein, during said transfer, the operation of the stationary static converter (11) is adapted as a function of steering data supplied by the onboard static energy converter (3).
- 30 9. The in-station power supply system (13) according to any one of the preceding claims 6 to 8, wherein:
 - the stationary static converter (11) has a transferred power characteristic of a value between 500 and 3000 kW.
- 35 10. The in-station power supply system (13) according to any one of the preceding claims 6 to 9, wherein the stationary static converter (11) includes a chopper.

11. The in-station power supply system (13) according to any one of the preceding claims 6 to 10, wherein the stationary static converter is reversible and is adapted to receive energy supplied by the onboard energy storage system in the vehicle.

12. An onboard energy storage system (7) of a railway vehicle (1), including an onboard static energy converter (3) and an energy storage module (2),
the onboard static energy converter (3) being adapted to transfer energy to the energy storage module by adapting the voltage (V2) supplied to the energy storage module (2) as a function of the charge state of said energy storage module,
in which the onboard static energy converter (3) is adapted to cooperate with a stationary static energy converter (11) located at a stop station of the vehicle, during an energy transfer done by the stationary static converter (11) to the onboard energy storage module (2), the onboard energy storage system (2) being charged as a function of the energy transferred at a voltage (V3) adapted by the stationary static converter.

13. The onboard energy storage system (7) according to claim 12, wherein, during an energy transfer by the stationary static converter (11) to the onboard energy storage module (2), the onboard static energy converter (3) is adapted to monitor the state of the energy storage module, and to steer the operation of the stationary static converter as a function of said monitored state.

14. The onboard energy storage system (7) according to claim 12 or 13, wherein:

- the onboard static energy converter (3) has a transferred power characteristic of a value between 300 and 500 kW.

15. The onboard energy storage system (7) according to any one of claims 12 to 14, wherein the onboard static energy storage converter (3) includes a chopper, and the energy storage module (2) includes ultracapacitors.

16. A railway vehicle (1) including an onboard energy storage system (7) according to any one of claims 12 to 15.