

**POWER SUPPLY INSTALLATION FOR A RAILWAY VEHICLE**

The invention relates to an installation for supplying electrical energy to public transport vehicles  
5 employing electric traction.

There is known in the art an installation for supplying electrical energy to a streetcar including a power supply device on board said streetcar. One such  
10 installation is described in patent application EP 0982 176 filed by the applicant. The onboard power supply device includes a flywheel. It is charged when the vehicle is stopped at a station to allow passengers to board and alight. The onboard power supply device of  
15 said streetcar is charged by a device external to the vehicle located at the station stop. When the vehicle leaves the station, it operates autonomously, with only the onboard power supply device powering the traction motors and the auxiliary equipment (air conditioning,  
20 lighting, etc.) of the vehicle in order for the vehicle to be able to travel between two station stops and to make passengers comfortable.

The applicant has carried out simulations of the energy  
25 consumed by a streetcar of this type, on a route marked out by such stations  $S_x$ ,  $S_y$ .

For example, a simulation was carried out for a streetcar 30 m long weighing 57 tonnes, fully laden and  
30 equipped with a flywheel-type power supply device on board the vehicle able to store a maximum of 4 kWh of energy and to deliver a maximum power of 200 kW. By fully laden vehicle is meant a vehicle conveying six persons per square meter.

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The vehicle used for the simulation also includes auxiliary equipment comprising all units consuming electrical energy that do not contribute to propulsion of the traction vehicle, for example onboard

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electronics, lighting, heating, air-conditioning compressor motors, passenger information systems, etc. The maximum power consumed by the auxiliary equipment is 63 kW, for example when the heating is operating at maximum power.

The above simulation was carried out for a particular route plan defined by the operator.

By route plan is meant the requirements of the operator in terms of transport system performance over a route defined by station stops  $S_x$ ,  $S_y$ . The trajectory of the vehicle starting at station stop  $S_x$  and traveling to station  $S_y$  and stopping there is denoted  $T_{xy}$ .

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These requirements are expressed as a function of the following criteria, for example:

- The speed profile on each trajectory between two station stops. By speed profile on the trajectory between two consecutive stations is meant the variation of the speed of the vehicle as a function of its position on the trajectory between two consecutive stations. In place of the speed profile, the operator defines, for example, a maximum time that the vehicle is allowed to take to cover the trajectory between two consecutive stations under normal operating conditions.
- The maximum time for which the vehicle stops at a station stop to enable passengers to board and alight and to charge the onboard power supply device.
- The level of comfort that it must be possible to provide for passengers. To be more precise, this refers to the power that the power supply installation is able to supply to the auxiliary equipment over each trajectory between two consecutive stations in order to operate the auxiliary equipment.
- Unexpected events, which the vehicle must be able to

cope with on the trajectories between two consecutive stations.

Unexpected events means events that the vehicle is  
5 liable to encounter on its trajectory and that lead to overconsumption of energy. This refers, for example, to the vehicle stopping at a crossroads at which the vehicle crosses the path of another vehicle, this stop not being preplanned. It may also refer to an  
10 unexpected stop imposed by a pedestrian crossing the track or a traffic jam.

For example, the operator may require the vehicle to be capable of unexpectedly stopping once between stations,  
15 restarting and accelerating to its cruising speed without its performance in terms of traction or passenger comfort deteriorating over the remainder of the trajectory.

20 To cope with an event of this type, the power supply installation must be able to make available to the motors and auxiliary equipment the energy necessary to power the vehicle during its unscheduled stop and to restart the vehicle and accelerate it to its cruising  
25 speed.

The results of the simulation of the energy consumed by the streetcar over the trajectories between two consecutive station stops are set out in Table A  
30 appended to this application. The route plan used to effect this simulation is as follows:

- The operator defines a maximum travel time  $t_{xy}$  of the vehicle over each trajectory  $T_{xy}$  between two consecutive stations  $S_x$  and  $S_y$ .
- 35 - The level of comfort required by the operator is equivalent to a mode of operation of the auxiliary equipment in which it consumes 63 kW over the whole of the route and thus over each trajectory. This mode

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of operation is equivalent to an energy  $Ea_{xy}$  expressed in kWh consumed by the auxiliary equipment over the trajectory  $T_{xy}$  equal to  $Ea_{xy} = 63 * t_{xy}/3600$ , where  $t_{xy}$  is expressed in seconds. This mode of operation is  
5 equivalent to operating the heating system at the maximum setting.

- The operator recommends coping with unexpected events as described in detail hereinafter without degrading operation, requiring the provision of a surplus  
10 energy  $Es_{xy}$  of 2.2 kWh over and above the energy consumed by the traction motors and the auxiliary equipment when the trajectory  $T_{xy}$  is traveled under normal operating conditions.

- The maximum stopping time  $ta_x$  in the station  $S_x$  is set  
15 so that the flywheel could always be charged completely in the station stop  $S_x$ . In energy terms, this amounts to stating that the flywheel stores an initial energy  $Ev'_x$  of 4 kWh when it starts in station  $S_x$  and can arrive at station  $S_y$  empty, with zero  
20 arrival energy  $Ev_y$ .

During the simulation, the applicant calculated the energy consumed by the equipment of the vehicle to travel the trajectory  $T_{xy}$  between two successive  
25 stations  $S_x$  and  $S_y$  complying with the route plan defined above:

- the energy  $Em_{xy}$  consumed by the traction motors,  
- the total energy  $Et_{xy}$  that the equipment must have available to cover the trajectory  $T_{xy}$  in compliance  
30 with the route plan, where  $Et_{xy} = Em_{xy} + Ea_{xy} + Es_{xy}$ ,  
- the energy  $Eb_{xy}$  consumed by the traction motors and the auxiliary equipment to cover the trajectory  $T_{xy}$  without encountering unexpected events.

35 The trajectory  $T_{xy}$  has an average gradient  $P_{xy}$  (expressed in %) and a length  $l_{xy}$  (expressed in meters).

It can be seen clearly that the energy  $Em_{xy}$  consumed by

the traction motors on a trajectory  $T_{xy}$  depends on the track profile on said trajectory and in particular the gradients and the distances to be traveled on those trajectories.

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By track profile over a trajectory  $T_{xy}$  is meant the evolution of the slope of the ground along the trajectory of the vehicle and the length  $l_{xy}$  of the trajectory  $T_{xy}$ .

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On comparing the trajectories  $T_{cd}$  and  $T_{ij}$  with lengths that are not very different but with average gradients that are very different, it is found that the energy  $Em_{cd}$  consumed by the traction motors is much lower than the energy  $Em_{ij}$ . The energy consumed by the traction motors is greater if the track is on an upgrade over this trajectory.

On comparing the energy consumed by the traction motors over the trajectories  $T_{jk}$  and  $T_{ij}$  the respective lengths of which are 423 m and 888 m and that have substantially identical average gradients, it is found that the longer the trajectory, the more energy is consumed by the traction motors.

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It is found that the energy  $E_{ab}$ ,  $E_{bc}$  and  $E_{ij}$  that the power supply installation must be able to make available to the vehicle to power the auxiliary equipment and the traction motors over the respective trajectories  $T_{ab}$ ,  $T_{bc}$  and  $T_{ij}$  so that the vehicle travels those trajectories in the respective times  $t_{ab}$ ,  $t_{bc}$ ,  $t_{ij}$  set by the operator are greater than over the rest of the trajectory of the vehicle. The trajectories  $T_{ab}$ ,  $T_{bc}$ ,  $T_{ij}$  respectively have a steep gradient, a long length and a long average length and a steep average gradient.

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The energies  $E_{ab}$ ,  $E_{bc}$  and  $E_{ij}$  are all three greater than the energy that the electrical installation can

make available to the traction motors and the auxiliary equipment over the trajectories  $T_{ab}$ ,  $T_{bc}$ ,  $T_{ij}$ . The energy that the electrical installation is capable of making available to the traction motors and the auxiliary  
5 equipment over the trajectories  $T_{xy}$ , on which the vehicle is powered only by the flywheel, is equal to  $Ev_{xy} = Ev'_x - Ev_y$ . Here,  $Ev_{xy}$  is equal to 4 kWh over the whole of the route of the vehicle.

10 In conclusion, the electrical installation is not capable of making sufficient energy available to the traction motors and the auxiliary equipment to cover the trajectories  $T_{ab}$ ,  $T_{bc}$ ,  $T_{ij}$  even if the vehicle does not encounter unexpected events on those trajectories.

15 Moreover, it is found that the prior art electrical installation is able to make available to the traction motors and the auxiliary equipment the necessary energy  $Et_{xy}$  for the vehicle to travel between two successive  
20 stations in compliance with the route plan only on the trajectory  $T_{hi}$  having a short length and a steep average downward gradient and for which the energy  $Et_{hi}$  is less than  $Ev_{hi}$ , i.e. 4 kWh.

25 Consequently, the vehicle does not have sufficient energy to comply with the route plan set by the operator over the trajectories  $T_{xy}$ , with the exception of the trajectory  $T_{hi}$ .

30 The applicant has usefully shown that the prior art electrical installation does not enable the vehicle to comply with the route plan over all the route of the vehicle and in particular over the trajectories between two successive stations on which the track profile has  
35 a long length and a steep upgrade.

One object of the present invention is to propose a rail vehicle power supply installation capable of

supplying sufficient energy to said vehicle to enable it to cover a route in compliance with a predetermined route plan.

5 To this end, the invention relates to a power supply installation for a rail vehicle, said vehicle including:

- at least one traction motor and at least one auxiliary equipment, and
- 10 - an energy storage device on board the vehicle, said onboard energy storage device being able to supply power to said at least one traction motor and said at least one auxiliary equipment, and being adapted:
- 15 - to be supplied with electrical energy when said vehicle is stopped at a station stop, and
- to cause said rail vehicle to travel on a track marked out by station stops,
- said installation being characterized in that a
- 20 ground power supply device is installed on at least a portion of the track between two successive station stops if the energy that the energy storage device is able to make available to said at least one traction motor and/or said at
- 25 least one auxiliary equipment on a trajectory  $T_{xy}$  between two successive station stops is insufficient to comply with a predefined route plan, said ground power supply device being able to power at least said energy storage device or
- 30 said at least one traction motor or said at least one auxiliary equipment when said vehicle is connected to said ground power supply device.

In particular embodiments of the invention, the power supply installation has one or more of the following

35 features, separately or in all technically possible combinations:

- a route plan defines on a trajectory  $T_{xy}$  between the

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two consecutive station stops:

- a travel time  $t_{xy}$  on a trajectory  $T_{xy}$ ,
- a maximum stopping time  $t_{ax}$  of the vehicle at the station stop  $S_x$ ,
- 5       - a passenger comfort level,
- unexpected events that said vehicle must be able to cope with;
- the ground power supply device does not extend over the whole length of the track between two consecutive
- 10       stations;
- a ground power supply device is disposed on a track portion between two consecutive stations on which the energy and/or the power liable to be consumed by said at least one traction motor is greater than over the
- 15       rest of the route;
- a ground power supply device is disposed on a track portion between two consecutive stations on which the energy and/or the power liable to be consumed by said at least one auxiliary equipment is greater than over
- 20       the rest of the route;
- a ground power supply device is disposed on a track portion between two consecutive stations, said track portion being on an upgrade;
- a ground power supply device is disposed on a track
- 25       portion between two consecutive stations, said track portion being an acceleration area in the route plan;
- a ground power supply device is disposed on a track portion between two consecutive stations, said track portion being an area in which the vehicle is liable to
- 30       encounter an unexpected event;
- a ground power supply device is disposed on a track portion between two consecutive stations, said track portion extending continuously over a track portion in which the vehicle is liable to stop and then restart
- 35       and accelerate;
- an onboard computer controls the operation of the electrical equipment of the vehicle at a point  $p$  of the trajectory  $T_{xy}$  between two successive stations and/or

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the lowering of pick-up means as a function of the following parameters:

- the state of charge  $Ev_p$  of the energy storage device at the point  $p$  on the trajectory  $T_{xy}$ ,
- 5 - the position  $p$  of the vehicle on the trajectory  $T_{xy}$ ,
- the amount  $Et_{py}$  of energy necessary to power the traction motors and the auxiliary equipment as far as the next station in compliance with the route plan,
- 10 - the amount  $Ev_{py}$  of energy that the energy storage device can make available to the traction motors and the auxiliary equipment as far as the station  $S_y$ ,
- 15 - the command from the driver control,
- the maximum current that the vehicle can draw from the ground power supply device;
- when the vehicle is connected to the ground power supply device an onboard computer is adapted to control
- 20 the supply of power to the electrical equipment of the vehicle by the ground power supply device in such a manner as:
  - to assist the energy storage device to power the traction motors and the auxiliary equipment,
  - 25 or
  - to power the energy storage device and the traction motor and the auxiliary equipment, or
  - to power only the traction motor and the auxiliary equipment
- 30 - the ground power supply device is segmented longitudinally into power supply segments separated by insulating segments, each insulating segment being supplied with electrical energy only when it is inside the footprint of the vehicle;
- 35 - in the route plan:
  - the travel time  $t_{xy}$  of a trajectory  $T_{xy}$  is between 30 seconds and 120 seconds;
  - the maximum stopping time  $t_{ax}$  of the vehicle at a

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- station stop is between 15 seconds and 35 seconds;
- the passenger comfort level corresponds to an energy between 18 kWh and 132 kWh;
  - the unexpected events with which said vehicle must be able to cope include at least one event consuming between 0.3 kWh and 2.2 kWh of energy.

The invention also provides a rail transport system including a rail vehicle, said vehicle being adapted to travel on a track marked out by station stops, said rail vehicle being supplied with power by a power supply installation.

The power supply installation of the invention has the advantage of being esthetically pleasing as there is no power supply by overhead line between the two station stops, which is increasingly important in town centers.

This system is less costly than a ground power supply system installed all along the route of the vehicle.

The vehicle power supply installation of the invention has the advantage of complying with the route plan defined by the operator regardless of the geography of the trajectory, i.e. the profile of the track between two consecutive stations.

The vehicle power supply installation of the invention also ensures that service is provided even if the vehicle encounters unexpected events.

The invention will be better understood after reading the following description, which is given by way of example only and with reference to the appended drawings and table, in which:

- Table A sets out the energy consumed by the vehicle, already partly described, lists the energy consumed and supplied by the equipment of the vehicle over a

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route extending from one station  $S_a$  to a station  $S_k$  marked out by stations  $S_x$  where  $x = b, c, d, e, f, g, h, i, j$ .

- 5 - Figure 1 is a diagrammatic representation of variations in the altitude in meters of a transport track and the disposition of the ground power supply device forming part of the power supply installation of the invention over the route of the vehicle between the station  $S_a$  and the station  $S_f$ .
- 10 - Figure 2 is a functional block diagram of a power supply installation of the invention with a vehicle situated on a track portion equipped with a ground power supply device, said track portion so equipped being adjacent a track portion with no ground power
- 15 supply device.

Figure 1 represents the track profile 5 over the route of the vehicle from the station  $S_a$  to the station  $S_f$  on a track 5.

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- The embodiment of the invention represented in figure 1 is adapted to anticipate shortages of energy for the equipment of the vehicle in order to supply sufficient energy to the vehicle to comply with the route plan
- 25 defined above over the whole of the route of the vehicle regardless of the track profile over the trajectory  $T_{xy}$ .

- As shown in figure 1, in a manner that is known in the art, the station stops  $S_x, S_y$  adapted to allow passengers to board and alight are equipped with an in-station charging device 18 represented in dashed outline in figure 1.

- 35 By in-station charging device 18 is meant a device for charging an energy storage system 15 and powering auxiliary equipment 12 when the vehicle is stopped at a station stop  $S_x$  and electrically connected to said

charging device.

The energy storage system 15 and the auxiliary equipment 12 are represented in figure 2 and are explained hereinafter.

According to the invention, the electrical installation includes a ground power supply device 19 equipping the equipped track portions 20 of the trajectories  $T_{ab}$ ,  $T_{bc}$ ,  $T_{cd}$ ,  $T_{ef}$ ,  $T_{ij}$ ,  $T_{jk}$ , said ground power supply device 19 being adapted to supply the vehicle with electrical energy when it is traveling over a track portion 20 equipped with said ground power supply device 19 as described in more detail hereinafter. An unequipped track portion 21 is a portion of the track 5 with no ground power supply device 19.

By supplying the vehicle with electrical energy is meant powering the electrical equipment of said vehicle. To be more precise, the ground power supply device 19 is adapted to power the energy storage system 15, the auxiliary equipment 12 and the traction motors 11.

The chosen locations of the ground power supply devices 19 in the first embodiment of the invention are described next.

As described in more detail hereinafter, in the embodiment shown in figure 2, the traction motors 11 of the vehicle are reversible. They are adapted to operate in consumer mode in which they supply traction energy to the wheels 4 of the vehicle 2 and in generator mode in which they generate a braking torque and are adapted to charge the energy storage system 15 on board the vehicle 2.

The remainder of the description describes a system

comprising a vehicle equipped with an onboard energy storage device consisting of a kinetic energy power supply device. The person skilled in the art will readily know how to replace this kinetic energy accumulator device with a supercapacitor- or battery-type device.

The vehicle energy consumption table thus includes the braking energy  $E_{f_{xy}}$ , which is the energy that the traction motors 11 are able to supply to the flywheel on the trajectory  $T_{xy}$  to charge it. The energy values  $E_{f_{xy}}$  on the trajectories  $T_{xy}$  were obtained by simulation.

The energy  $E_{r_{xy}}$  is the real energy that the electrical installation must be able to supply to the vehicle 2 in compliance with the route plan on the trajectory  $T_{xy}$ , a braking energy  $E_{f_{xy}}$  being used to charge the flywheel on the trajectory  $T_{xy}$ .

$$E_{r_{xy}} = E_{t_{xy}} - E_{f_{xy}}.$$

In the embodiment described, the equipped trajectories are the trajectories  $T_{ab}$ ,  $T_{bc}$ ,  $T_{cd}$ ,  $T_{ef}$ ,  $T_{ij}$ ,  $T_{jk}$  on which the energies  $E_{r_{ab}}$ ,  $E_{r_{bc}}$ ,  $E_{r_{cd}}$ ,  $E_{r_{ef}}$ ,  $E_{r_{ij}}$ ,  $E_{r_{jk}}$  are higher than the energies  $E_{v_{ab}}$ ,  $E_{v_{bc}}$ ,  $E_{v_{cd}}$ ,  $E_{v_{ef}}$ ,  $E_{v_{ij}}$ ,  $E_{v_{jk}}$  that the onboard flywheel 15 is able to make available to the vehicle 2 on the respective trajectories  $T_{ab}$ ,  $T_{bc}$ ,  $T_{cd}$ ,  $T_{ef}$ ,  $T_{ij}$ ,  $T_{jk}$ .

Figure 1 shows only the trajectories  $T_{ab}$ ,  $T_{bc}$ ,  $T_{cd}$ ,  $T_{ef}$ .

The energy  $E_{v_{xy}}$  that the kinetic energy accumulator system 15 is able to make available to the vehicle 2 on a trajectory  $T_{xy}$  is determined by the route plan and here is equal to the maximum energy that the kinetic energy accumulator system 15 is able to store, i.e. 4 kWh, because the maximum stopping time  $t_{ax}$  in a station stop  $S_x$  is sufficient to charge completely the kinetic energy accumulator device 15.

Ground power supply devices 19 are therefore provided outside the station stops on portions of the track 5 of the trajectories  $T_{ab}$ ,  $T_{bc}$ ,  $T_{cd}$ ,  $T_{ef}$ ,  $T_{ij}$ ,  $T_{jk}$  to supply the vehicle 2 with power when it is on the track portion 20 equipped with said ground power supply device 19.

In particular, a ground power supply device 19 equips at least a portion of the track on a trajectory  $T_{xy}$  between two consecutive stations on which the energy  $Ev_{xy}$  that the kinetic energy accumulator system 15 is able to make available to the vehicle 2 is insufficient to power the traction motors 11 and the auxiliary equipment 12 in compliance with the route plan defined by the operator.

As explained in more detail hereinafter, the ground power supply devices are preferably installed on track portions in which the traction motors and/or the auxiliary equipment are liable to consume more power than over the rest of the trajectory. To be more precise, a ground power supply device 19 preferably equips portions of the track 5 on an upgrade in the direction of movement of the vehicle and portions of the track 5 on which it is highly probable that the vehicle will accelerate and/or make an unexpected stop.

To this end, as can be seen in figure 1, a track portion 20 equipped with a ground power supply device 19 extends over the entire length of the trajectory  $T_{ab}$ .

The energy  $Er_{ab}$  that the installation must be able to supply to the vehicle is 9.51 kWh, which is more than twice the energy  $Ev_{ab}$ . The whole of the track 5 between the stations  $S_a$  and  $S_b$  is therefore equipped with a ground power supply section. It is important to note that the track portion R1 equipped with a ground power supply device 19 between the stations  $S_a$  and  $S_b$  is on

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average on an upgrade in the direction of the trajectory  $T_{ab}$ . The adjacent track in the opposite direction is not equipped with a ground power supply device because the track is on an overall downgrade in the direction of the trajectory  $T_{ba}$ . Adjacent tracks on which the vehicle travels in opposite directions are not both equipped, which makes it possible to propose an economical system.

The energy requirements of the vehicle on the trajectory  $T_{ab}$  are high because the upgrade is particularly steep on this trajectory. The motors consume a great deal of energy on this trajectory to supply potential energy to the vehicle in addition to the kinetic energy necessary for it to move.

A track portion R2 between the stations  $S_b$  and  $S_c$  is equipped with a ground power supply device 19. Because the trajectory  $T_{bc}$  is long, the energy  $Ev_{bc}$  that the kinetic energy accumulator system 15 can make available to the vehicle on the trajectory  $T_{bc}$  is less than the energy that the electrical installation must be able to make available to the vehicle to cover the trajectory  $T_{bc}$  in compliance with the route plan.

A track portion 20 between the stations  $S_b$  and  $S_c$  is equipped with a ground power supply device 19. This track portion R2 extends continuously over the entire length of the intersection I and to either side of the intersection I.

The energy that must be available to the traction motors and the auxiliary equipment to comply with the route plan on the trajectory  $T_{bc}$  is 4.63 kWh, which is not very much higher than the energy  $Ev_{bc}$  that the flywheel has to make available to the vehicle on the trajectory  $T_{bc}$ .

By intersection is meant an area in which the streetcar track crosses a road, said track being liable to be crossed in this area by a vehicle traveling on the road. There is a high probability of the rail vehicle  
5 being obliged to stop before or on said intersection to avoid colliding with a vehicle or a pedestrian crossing the intersection.

This type of stop consumes energy because it lengthens  
10 the duration of the trajectory, which increases the consumption of the auxiliary equipment and imposes a restart followed by acceleration of the vehicle. This acceleration causes consumption of power and energy by the traction motors.

15 A track portion 20 between the stations  $S_c$  and  $S_d$  is equipped with a ground power supply device 19. In this upgrade track portion R3 there is a high probability that the traction motors 11 will consume a great deal  
20 of energy to overcome gravity and to propel the vehicle at a suitable speed.

Alternatively, a ground power supply device 19 is provided on a portion of the track 5 between the  
25 stations  $S_c$  and  $S_d$  that is level or on a downgrade but is defined in the route plan as an acceleration area. The traction motors 11 consume energy in an area defined in the route plan as an acceleration area.

30 The track has no ground power supply device 19 between the stations  $S_d$  and  $S_e$  because the energy  $E_{v_{de}}$  that the flywheel is able to make available to the vehicle on the trajectory  $T_{de}$  is greater than the energy  $E_{r_{de}}$  that the vehicle must have available on the trajectory  $T_{de}$  to  
35 comply with the route plan.

The track portion 20 is equipped with a ground power supply device 19 between the two stations  $S_e$  and  $S_f$  and

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this track portion R4 is a level area defined as an acceleration area in the route plan.

5 The structure of the power supply installation for the rail vehicle 2 adapted to travel on parallel metal rails, not shown, is described next.

10 The vehicle 2 comprises a passenger cabin 3 supported by a set of wheels 4. The rails of the track are adapted to support and guide the wheels 4.

15 Alternatively, the vehicle 2 comprises a succession of cars each having a cabin 3 and at least two of which are supported by wheels 4.

20 The power supply installation of the invention is adapted to supply electrical energy to electric traction motors 11 and to auxiliary equipment 12 via a DC power bus 7.

The driving wheels 4 are driven by electric motors 11 supplied with power by traction converters that for clarity are not shown.

25 The traction converters are adapted to convert the DC voltage supplied by the power bus 7 into an AC motor supply voltage. The combination of the traction motors 11 and the traction converters constitutes the traction system of the vehicle.

30 The auxiliary equipment 12 includes all units consuming electricity that do not contribute to propelling the traction vehicle 2, for example onboard electronics, lighting, air conditioning, passenger information  
35 system, heating system, etc.

The vehicle 2 is shown as comprising only one car. In the case of a vehicle comprising a plurality of cars,

the electrical equipment 7, 11, 12 is divided between the cars of the vehicle 2, for example.

5 The electric motors 11 are reversible. The traction electric motors 11 are either supplied with power by the power bus 7 or generate a braking torque supplying electrical energy to the traction converters, which convert the AC voltage generated by the traction motors 11 to produce a DC voltage on the power bus 7.

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The vehicle 2 carries an onboard kinetic energy accumulator device 15 adapted to accumulate energy in the form of kinetic energy and to restore it in the form of electrical energy. In a manner that is known in the art, the energy storage device 15. The energy storage device of the embodiment described is a kinetic energy accumulator device that includes a motor with a rotor that serves as an inertia mass. Alternatively, the onboard energy storage device can be any other storage device, such as a supercapacitor or battery device.

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The onboard kinetic energy accumulator device 15 is adapted to operate in a discharge regime when supplying power to the auxiliary equipment 12 and/or the traction motors 11 and in a charge regime during charging phases. An onboard computer 38 controls the switching of the kinetic energy accumulator device 15 from one mode of operation to the other.

30

In the discharge regime, the kinetic energy accumulator device 15 behaves as a generator and produces a DC voltage on the power bus 7.

35 In the charge regime, the kinetic energy accumulator device 15 behaves as a motor and takes electrical energy from the power bus 7. The DC voltage is converted by a converter in the kinetic energy

accumulator device 15 into an AC supply voltage for the flywheel of the kinetic energy accumulator device 15.

5 The phases of charging the kinetic energy accumulator device 15 are for example the phases of braking the vehicle during which the traction motors 11 operate in generator mode.

10 In a manner that is known in the art, the kinetic energy accumulator device 15 is equipped with means, not shown, for measuring the energy stored in said device 15.

15 The power supply installation includes in the conventional way means for measuring the position of the vehicle along its route. For example, the measuring means are means for measuring the speed of the traction motors, from which the speed of the traction vehicle and its position on the route can be determined, or GPS  
20 means for determining the location of the vehicle.

In a conventional way, the vehicle includes means for picking up energy from the in-station charging device 18, not shown, adapted to make an electrical connection  
25 between the power supply bus 7 and the in-station charging device 18 when the vehicle is stopped at a station stop.

30 The in-station charging device 18 is adapted to charge the kinetic energy accumulator device 15 and to power the auxiliary equipment 12 when the vehicle is stopped at a station stop  $S_x$  by supplying electrical energy to the power bus 7.

35 For example, the in-station charging device 18 includes for example an overhead line extending along the station stop and the means for picking up energy include a pantograph electrically connected to the

vehicle 2 and to be more precise to the power bus 7, for example. One such charging device is described in the applicant's patent application EP0982176 A1.

5 Instead of an overhead line, the in-station charging device 18 can include any other power supply means that can be connected to the vehicle by energy pick-up means. Such power supply means include a third rail or a ground power supply device at the station stop, for  
10 example.

The installation for supplying power to the vehicle includes a ground power supply device 19 equipping portions of the track 5 outside the stations, as shown  
15 in figure 2.

One such ground power supply device 19 is described in the document FR 2762810.

20 As shown in figure 2, the ground power supply device 19 is incorporated in the roadway between the two rails of the vehicle track and extends along and parallel to the two track rails. The ground power supply device is flush with the surface of the track 5.

25 In a manner that is known in the art, the ground power supply device 19 is segmented longitudinally into power supply segments 34 separated by insulating segments 36.

30 The ground power supply device 19 is connected via electrical substations, not shown, to the electrical distribution grid of the town. To prevent any risk of electrocuting pedestrians, each power supply segment 34 is supplied with electrical energy only when it is  
35 inside the footprint of the vehicle 2.

To be more precise, the ground power supply device 19 is adapted to supply energy to the vehicle 2 when at

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least one segment 34 is inside the footprint of the vehicle 2 and at least one energy pick-up means 22 carried by the vehicle 2 are in physical contact with at least one of the segments 34 supplied with electrical energy.

As can be seen in figure 2, the vehicle 2 is equipped with means 22 for picking up electrical energy from the ground power supply device 19.

The electrically conductive pick-up means 22 are fixed to the vehicle. The pick-up means 22 provide a mechanical and electrical connection between the vehicle and the ground power supply device 19.

The pick-up means 22 comprise two shoes that are adapted to move between a raised position, not shown, in which the pick-up means 22 are not in physical contact with the ground surface of the track 5, and a lowered position, shown in figure 2, in which the shoes are in sliding contact with the surface of the track 5, in particular with power supply segments 34 and insulating segments 36 if the vehicle 2 is located on a portion 20 of the track 5 equipped with a ground power supply device 19.

The spacing between the shoes of the pick-up means 22 is greater than the length of an isolating segment 36 to ensure continuous supply of power from the bus 7 via the shoes, at least one of which is connected to the conductive segment 34.

In this way, as explained hereinafter, the ground power supply device 19 is able to power the kinetic energy accumulator device 15, the auxiliary equipment 12 and the traction motors 11 when an electrical connection between at least one segment 34 and the power bus 7 is made via the electrical energy pick-up means.

As shown in figure 2, the power supply installation includes an onboard data network 37 connected to an onboard computer 38. The computer 38 is connected to a driver control 39.

The onboard computer 38 receiving an instruction from the driver control 39 controls the operation of the traction motors 11, the auxiliary equipment 12 and the kinetic energy accumulator device 15 via the onboard network.

The driver control 39 is a manipulator device that the driver can move to send a traction, braking or idle command to the onboard computer 38.

A traction command is sent when the motors require energy, for example during acceleration or on an upgrade. In this case, the onboard computer 38 commands powering of the traction motors 11 by absorption of energy from the power bus 7 so that the traction motors 11 generate a traction torque to propel the vehicle.

An idle command is sent if the traction motors 11 do not require energy. The vehicle is either stopped or coasting.

When the driver control sends a braking command to the onboard computer 38, the computer commands selection of the braking mode of the motors 11 and feeding of the power bus 7 with the electrical energy generated by the traction motors in braking mode.

Alternatively, the driver control 39 is an automatic control device for sending the onboard computer traction or braking commands.

The operation of the power supply installation is

described next.

The operation of the electrical installation is controlled by the onboard computer 38, which has access to information on the power supply, the energy pick-up means 22, the position of the vehicle 2 on its route, the state of charge of the kinetic energy accumulator, the route plan, the driver control 39 and the power requirements of the auxiliary equipment.

10

The onboard computer 38 advantageously has access to a table of energy values listing, for each point on the route of the vehicle, the energy that the vehicle 2 requires to reach the next station stop  $S_x$  in compliance with the route plan. These values are obtained either by simulation or by averaging values obtained during preliminary tests.

When the vehicle is stopped at a station stop  $S_x$ , the onboard computer 38 controls charging of the kinetic energy accumulator device 15 and of the auxiliary equipment 12 by the in-station charging device 18, which supplies electrical energy to the traction bus 7, the charging device 18 being connected to the bus 7 by energy pick-up means of the charging device 18 that are not shown.

When the vehicle leaves the station  $S_x$ , the kinetic energy accumulator device 15 has available an amount  $Ev_x$  of energy depending on the route plan and more particularly on the time for which the vehicle stopped at the station stop  $S_x$  and the energy available to the kinetic energy accumulator device 15 on arriving at the station stop  $S_x$ .

35

When the vehicle is between two consecutive stations  $S_x$  and  $S_y$  on a track portion 21 with no ground power supply device 19, the vehicle 2 is autonomous.

In braking mode, when the driver control 39 sends a braking command, the onboard computer 38 controls recovery of the braking energy to supply the kinetic energy accumulator device 15 and the auxiliary equipment with energy supplied to the power bus 7 by the traction motors 11.

In traction mode, the onboard computer 38 manages the supply of power to the traction motors 11 and the auxiliary equipment 12 by the kinetic energy accumulator device 15, which is in discharge mode at this time and delivers electrical energy to the power bus 7.

Before the vehicle reaches a track portion 20 equipped with a ground power supply device 19, the driver is alerted by a signaling device, not shown, to command lowering of the pick-up means 22. The pick-up means 22 are lowered when the vehicle 2 is on a track portion 20 equipped with a ground power supply device 19 to establish physical contact between said pick-up means 22 and the at least one power supply segment 34 in line with said pick-up means 22.

Alternatively, the onboard computer 38 commands lowering of the shoe.

The onboard computer 38 implements a power supply process to manage the energy picked up by the vehicle 2 from the ground power supply device 19.

At any point on the trajectory  $T_{xy}$  the onboard computer 38 is able to manage circulation of energy in the vehicle 2 and operation of the electrical equipment (15, 11, 12) of the vehicle as a function of:

- the state of charge of the flywheel, i.e. the amount  $Ev_p$  of energy contained in the kinetic energy

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accumulator device at the point  $p$  on the trajectory  $T_{xy}$ ,

- the position  $p$  of the vehicle on the trajectory  $T_{xy}$ ,
- the amount  $Et_{py}$  of energy necessary to supply power to  
5 the traction motors 11 and the auxiliary equipment 12  
as far as the next station in compliance with the  
route plan,
- the amount  $Ev_{py}$  of energy that the kinetic energy  
accumulator device 15 can make available to the  
10 traction motors 11 and the auxiliary equipment 12 as  
far as the station  $S_y$ ,
- the command from the driver control 39,
- the maximum current that the vehicle can draw from  
the ground power supply device, such as to comply  
15 with the predetermined route plan.

In the remainder of the description it is assumed that  
the pick-up means 22 are lowered and that the vehicle  
is moving on an equipped track portion 20.

20

When the vehicle 2 is stopped at the station  $S_a$ , the  
onboard computer 38 controls charging of the flywheel  
14 and supply of power to the auxiliary equipment 12 by  
the in-station charging device 18.

25

The route plan described above providing a sufficiently  
long stopping time to charge the kinetic energy  
accumulator device 15 completely at the station stop  $S_a$ ,  
the flywheel is totally charged on leaving the station  
30  $S_a$ .

On the track portion  $R1$  extending over the whole of the  
trajectory  $T_{ab}$ , the traction motors 11 and the auxiliary  
equipment 12 are supplied with power over the whole of  
35 the trajectory  $T_{ab}$  by the ground power supply device 19  
as a function of their respective energy requirements.

Referring to the table of power consumption of the

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vehicle 2, it is seen that the vehicle 2 requires energy that the APS device can supply to it on the track section R2 only if the vehicle encounters an unexpected event on its trajectory that consumes more than 0.63 kWh of energy, the amount  $E_{r_{xy}}$  of energy being equal to 4.63 kWh. On the track section R2, the ground power supply device 19 is able to supply energy to the vehicle 2 via the pick-up means 22 in electrical contact with at least one power supply segment 34.

10

When the vehicle is on the track portion R2, two situations can arise. Either the vehicle encounters an unexpected event or it does not.

15 If the vehicle 2 has encountered an unexpected event at the intersection I, it has been obliged to stop before the intersection I.

When the vehicle 2 stops before the intersection I, and when the vehicle starts and accelerates, the auxiliary equipment 12 and the kinetic energy accumulator device 15 are supplied with power by the ground power supply device 19. On the track portion R2, the onboard computer 38 compares the state of charge  $E_{vp}$  of the kinetic energy accumulator device 15 to the amount  $E_{t_{py}}$  of energy necessary to reach the next station stop  $S_c$  in compliance with the route plan and commands charging of the kinetic energy accumulator device 15 if the remaining energy in the kinetic energy accumulator device 15 is insufficient to reach the next station with an amount  $E_{vc}$  of energy and in compliance with the route plan.

This embodiment has the advantage that it does not discharge the kinetic energy accumulator device 15 at a place where the traction motors 11 are liable to consume a lot of power. A lot of energy can also be consumed on the track portion 20 equipped with the

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ground power supply device 19. Here, if the vehicle makes an unexpected stop at the intersection I, the traction motors 11 consume a lot of power to start and accelerate the vehicle 2.

5

In a second embodiment, the vehicle draws limited power from the ground power supply device. Thus when the vehicle 2 starts and accelerates, the onboard computer 38 commands supply of power to the auxiliary equipment 12 by the ground power supply device 19 whereas the traction motors 11 are supplied with power by means of the ground power supply device 19 and the kinetic energy accumulator device 15 simultaneously.

15 This embodiment has the advantage that it draws a reasonable power and therefore a reasonable current from the ground power supply device 19 as well as limiting the energy that the kinetic energy accumulator device 15 supplies to the traction motors 11 and thus  
20 limiting the discharging of the kinetic energy accumulator device 15.

Providing the ground power supply device 19 at a place where a lot of power is liable to be consumed by the  
25 traction motors 11, here an intersection, limits the discharging and/or charging of said kinetic energy accumulator device 15 at a place where it would be liable to be discharged a lot.

30 If the vehicle has not encountered an unexpected event at the intersection I and the kinetic energy accumulator device 15 is storing sufficient energy to reach the station  $S_c$  with an amount  $Ev_c$  of energy in compliance with the route plan, the onboard computer 38  
35 nevertheless commands charging of the kinetic energy accumulator device 15 and supply of power to the traction motors 11 and the auxiliary equipment 12 by the ground power supply device 19.

This charges the kinetic energy accumulator device 15 and for the remainder of the trajectory  $T_{bc}$  either provides surplus energy available in the event of  
5 another unexpected event on the trajectory  $T_{bc}$  or a breakdown of the in-station charging device 18 at the station  $S_c$  or reduces the stopping time at the station  $S_c$  to charge the flywheel 14 with an amount  $Ev'_c$  of energy.

10

Alternatively, if the vehicle 2 has not encountered an unexpected event at the intersection I and the kinetic energy accumulator device 15 is storing sufficient energy to reach the station stop  $S_c$  with an amount  $Ev_c$   
15 of energy in compliance with the route plan, the onboard computer 38 commands supply of power to the traction motors 11 and the auxiliary equipment 12 by the kinetic energy accumulator device 15. Thus no energy is drawn from the ground power supply device in  
20 the track portion R2.

When the vehicle 2 is on the point of leaving the track portion 20 equipped with the ground power supply device 19, the driver receives an instruction via a signaling  
25 device to command raising of the pick-up means 22.

Alternatively, the pick-up means 22 are raised automatically when the vehicle leaves the track portion  
20.

30

If the vehicle brakes on the track portion R2, the onboard computer 38 commands charging of the kinetic energy accumulator device 15 and supply of power to the auxiliary equipment 12 by the ground power supply  
35 device 19 and/or the traction motors 11.

On the track portion R3, which is an upgrade in the direction of movement of the vehicle 2, the onboard

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computer 38 can command either charging of the kinetic energy accumulator device 15 and powering of the auxiliary equipment 12 and the traction motors 11 or of powering the traction motors 11 and the auxiliary equipment 12 without charging the kinetic energy accumulator device 15.

These two strategies have the advantage of not discharging the kinetic energy accumulator device 15 at a location where a lot of power and energy are consumed by the traction motors 11 because of the upgrade. Moreover, the two strategies have the advantages of charging the kinetic energy accumulator device 15 and of not drawing excessive power from the ground power supply device 19.

The track portion R4 is a level area of the track defined as an acceleration area in the route plan.

In the track portion R4, the onboard computer 38 can command either charging of the kinetic energy accumulator device 15 and powering of the traction motors 11 and the auxiliary equipment, or of powering the traction motors 11 and the auxiliary equipment 12 without charging the kinetic energy accumulator device 15.

When the vehicle 2 is on a track portion 20 equipped with a ground power supply device 19, the onboard computer 38 can use a number of strategies that comply with the route plan for operating the equipment of the vehicle and circulating energy in the vehicle. This has the advantage of improving the quality of the power supply installation as a function of the priorities of the operator (drawing a low current from the ground power supply device, limiting the stopping time at stations, having maximum energy available to cope with unexpected events).

Alternatively, when the vehicle traveling on a trajectory  $T_{xy}$  reaches a track portion 20 equipped with a ground power supply device 19, the onboard computer 38 commands lowering of the pick-up means 22 only on reaching the equipped track portion 20, the energy contained in the kinetic energy accumulator device 15 being insufficient to power the traction motors 11 and the auxiliary equipment 12 as far as the station  $S_y$  in compliance with the route plan determined by the operator.

The route plan of the vehicle is such that:

- in the route plan,
  - the travel time  $t_{xy}$  on a trajectory  $T_{xy}$  is between 30 seconds and 120 seconds, preferably 60 seconds;
  - the maximum stopping time  $t_{ax}$  of the vehicle at a station stop is between 15 seconds and 35 seconds, preferably 20 seconds;
  - the passenger comfort level corresponds to an energy between 18 kWh if there is no air conditioning or heating and 132 kWh if there is air conditioning, for example;
  - the unexpected events with which said vehicle must be able to cope include at least one event consuming between 0.3 kWh and 2.2 kWh of energy, which is for example the energy consumed by an unscheduled stop of one minute duration.

**CLAIMS**

1. A power supply installation for a rail vehicle (2), said vehicle (2) including:
  - 5 - at least one traction motor (11) and at least one auxiliary equipment (12), and
  - an energy storage device (15) on board the vehicle (2), said onboard energy storage device (15) being able to supply power to said at least  
10 one traction motor (11) and said at least one auxiliary equipment (12),  
and being adapted:
    - to be supplied with electrical energy when said vehicle (2) is stopped at a station stop ( $S_x$ ),  
15 and
    - to cause said rail vehicle (2) to travel on a track (5) marked out by station stops ( $S_x$ ),  
said installation being characterized in that a ground power supply device (19) is installed on at  
20 least a portion of the track (5) between two successive station stops ( $S_x$ ,  $S_y$ ) if the energy that the energy storage device (15) is able to make available to said at least one traction motor (11) and/or said at least one auxiliary equipment  
25 (12) on a trajectory  $T_{xy}$  between two successive station stops ( $S_x$ ,  $S_y$ ) is insufficient to comply with a predefined route plan, said ground power supply device (19) being able to power at least said energy storage device (15) or said at least  
30 one traction motor (11) or said at least one auxiliary equipment (12) when said vehicle (2) is connected to said ground power supply device (19).
2. The rail vehicle power supply installation as  
35 claimed in claim 1, characterized in that a route plan defines on a trajectory  $T_{xy}$  between the two consecutive station stops ( $S_x$ ,  $S_y$ ):
  - a travel time  $t_{xy}$  on a trajectory  $T_{xy}$ ,

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- a maximum stopping time  $t_{ax}$  of the vehicle at the station stop  $S_x$ ,
- a passenger comfort level,
- unexpected events that said vehicle (2) must be able to cope with.

- 5
3. The rail vehicle power supply installation as claimed in either of the preceding claims, characterized in that the ground power supply device (19) does not extend over the whole length of the track (5) between two consecutive stations ( $S_x$ ,  $S_y$ ).
- 10
4. The rail vehicle power supply installation as claimed in any of the preceding claims, characterized in that a ground power supply device (19) is disposed on a track portion (5) between two consecutive stations ( $S_x$ ,  $S_y$ ) on which the energy and/or the power liable to be consumed by said at least one traction motor (11) is greater than over the rest of the route.
- 15
- 20
5. The rail vehicle power supply installation as claimed in any of the preceding claims, characterized in that a ground power supply device (19) is disposed on a track portion (5) between two consecutive stations ( $S_x$ ,  $S_y$ ) on which the energy and/or the power liable to be consumed by said at least one auxiliary equipment (12) is greater than over the rest of the route.
- 25
- 30
6. The rail vehicle power supply installation as claimed in any of the preceding claims, characterized in that a ground power supply device (19) is disposed on a track portion (5) between two consecutive stations ( $S_x$ ,  $S_y$ ), said track portion (5) being on an upgrade.
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7. The rail vehicle power supply installation as claimed in any of the preceding claims, characterized in that a ground power supply device (19) is disposed on a track portion (5) between two consecutive stations ( $S_x$ ;  $S_y$ ), said track portion (5) being an acceleration area in the route plan.
8. The rail vehicle power supply installation as claimed in any of the preceding claims, characterized in that a ground power supply device (19) is disposed on a track portion (5) between two consecutive stations ( $S_x$ ;  $S_y$ ), said track portion (5) being an area in which the vehicle is liable to encounter an unexpected event.
9. The rail vehicle power supply installation as claimed in any of the preceding claims, characterized in that a ground power supply device (19) is disposed on a track portion (5) between two consecutive stations ( $S_x$ ;  $S_y$ ), said track portion (5) extending continuously over a track portion in which the vehicle is liable to stop and then restart and accelerate.
10. The vehicle power supply installation as claimed in any of the preceding claims, characterized in that an onboard computer (38) controls the operation of the electrical equipment (11, 12, 15) of the vehicle at a point p of the trajectory ( $T_{xy}$ ) between two successive stations ( $S_x$ ) and ( $S_y$ ) and/or the lowering of pick-up means (22) as a function of the following parameters:
- the state of charge of the flywheel, i.e. the amount  $Ev_p$  of energy contained in the energy storage device (15) at the point p on the trajectory  $T_{xy}$ ,
  - the position p of the vehicle on the trajectory

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 $T_{xy}$ ,

- the amount  $Et_{py}$  of energy necessary to power the traction motors (11) and the auxiliary equipment (12) as far as the next station in compliance with the route plan,
  - the amount  $Ev_{py}$  of energy that the energy storage device (15) can make available to the traction motors (11) and the auxiliary equipment (12) as far as the station  $S_y$ ,
  - the command from the driver control (39),
  - the maximum current that the vehicle can draw from the ground power supply device (19).
11. The power supply installation as claimed in the preceding claim characterized in that when the vehicle is connected to the ground power supply device (19) an onboard computer (38) is adapted to control the supply of power to the electrical equipment (11, 12, 15) of the vehicle by the ground power supply device (19) in such a manner as:
- to assist the energy storage device (15) to power the traction motors (11) and the auxiliary equipment (12), or
  - to power the energy storage device (15) and the traction motor (11) and the auxiliary equipment (12), or
  - to power only the traction motors (11) and the auxiliary equipment (12).
12. The power supply installation as claimed in the preceding claim, characterized in that the ground power supply device (19) is segmented longitudinally into power supply segments (34) separated by insulating segments (36), each insulating segment being supplied with electrical energy only when it is inside the footprint of the vehicle (2).

13. The rail vehicle power supply installation as claimed in any of claims 2 to 11, characterized in that in the route plan:
- 5       - the travel time  $t_{xy}$  of a trajectory  $T_{xy}$  is between 30 seconds and 120 seconds;
- the maximum stopping time  $t_{ax}$  of the vehicle at a station stop is between 15 seconds and 35 seconds;
- 10       - the passenger comfort level corresponds to an energy between 18 kWh;
- the unexpected events with which said vehicle must be able to cope include at least one event consuming between 0.3 kWh and 2.2 kWh of energy.
- 15
14. A rail transport system including a rail vehicle (2), said vehicle (2) being adapted to travel on a track (5) marked out by station stops ( $S_x$ ), said rail vehicle (2) being supplied with power by a
- 20       power supply installation according to any of the preceding claims.