

ELECTRICALLY POWERED TRANSPORT SYSTEM

Technical field of the invention

5 [001] The present invention relates to an electrically powered transport system and to a method for managing electrical energy in such an electrically powered transport system.

Prior art

[002] Nowadays, various solutions for driving a transport system are recognized. A first, 10 conventional solution consists in using fossil fuel- or gas-powered combustion engines. A second, more recent solution consists in using a hybrid system in which a combustion engine is combined with an electric motor, with a device for managing the transition from one to the other. Lastly, a third solution consists in using a fully electric system, including one or more electric motors supplied with power by batteries.

15 [003] It turns out that the drive solutions using only electric motors supplied with power by batteries have advantages in certain applications. This is the case in particular in transport systems with a plurality of vehicles, referred to as trains of vehicles, which are used for transporting loads in the construction of infrastructure. This is the case for example with infrastructure such as tunnels where the structure extends as work progresses. Specifically, 20 for such infrastructure, it is important to have access to a fully energy-autonomous solution which also does not pollute directly like the combustion or hybrid solutions. Patent application **FR3024703A1** describes such an electrically powered transport system solution.

[004] This patent application describes in particular a transport system composed of a train of a plurality of vehicles that are coupled to one another and include a top vehicle and a tail 25 vehicle, each of which is provided with a driver cab so that the system is able to move in both directions without having to turn around. Each vehicle is driven by its own electric drive assembly. Each electric drive assembly includes at least one electric motor for driving the wheels of the vehicle, a converter for controlling the electric motor and an electrical energy storage module for supplying the motor with electrical energy.

30 [005] The solution described in this document provides in particular means for transferring electrical energy between the electrical energy storage modules of the transport system. These means make it possible for example to transfer electrical energy directly from one electrical energy storage module to another electrical energy storage module in order to balance the state of charge between the two modules. This involves for example driving the 35 discharging of an electrical energy storage module having a state of charge of more than 70% into an electrical energy storage module having a state of charge of less than 30%. To achieve such a transfer of electrical energy, the solution therefore requires:

- the modules to be connected to one another by power connections;
- converters and means for driving the converters to be used to transfer power 40 between the modules.

[006] It is thus understood that when such a solution is to be duplicated for all of the modules, it may prove to be complex to implement, bulky and expensive.

[007] Document **US2015/0204741A1** describes a system comprising a vehicle to which a trailer is attached. The proposed solution allows the operating behavior of a vehicle to which a trailer is attached to be simulated. The simulation is aimed in particular at a vehicle provided with a traction battery. The vehicle includes a traction battery for supplying its electric motor with power.

[008] The trailer also includes a traction battery and an electric motor. The battery of the trailer is capable of supplying the motor of the vehicle with power and of charging the battery of the vehicle. The electric motor of the trailer may operate in braking mode. The electrical energy produced when braking may be used to charge the battery of the vehicle or the battery of the trailer. It may also be dissipated into a dissipation system.

[009] In this solution, the two batteries have a power connection between them, it being possible to transfer energy from one to the other. This energy transfer principle does not allow a modular solution, in which the two drive systems, on the trailer side and on the vehicle side, are independent, to be obtained.

[010] A first object of the invention is therefore to provide a solution that makes it possible, in an electrically powered transport system, to transfer electrical energy from one electrical energy storage module to another electrical energy storage module without having to use a power connection between the modules or energy transfer means such as described in the prior art.

Summary of the invention

[011] This first object is achieved by an electrically powered transport system including:

- a plurality of rolling assemblies;
- a plurality of electric drive assemblies, each of which is associated with a distinct rolling assembly, each electric drive assembly comprising:
 - o at least one electric motor for driving said assembly for rolling on the ground in rotation;
 - o at least one electrical energy storage module that is intended to supply said electric motor with electrical energy and that includes a plurality of electrical energy storage cells;
 - o at least one bidirectional voltage converter that is arranged to control a transfer of electrical energy between said electrical energy storage module and said electric motor in a motor mode or a transfer of energy from the electric motor to the electrical energy storage module in a generator mode;
- the electrical energy storage module of each electric drive assembly having no electrical power connection with the electrical energy storage module of each other electric drive assembly;

- processing and management means that are arranged to manage each electrical energy storage module and to control each converter of said electric drive assemblies,
- the processing and management means including:
 - 5 ○ means for determining a request to run at least one management function within each electrical energy storage module;
 - means for determining a sequence to be applied to the electrical energy storage module according to said management function determined for this module; and in that
 - 10 ○ for a first module of a first electric drive assembly of the system, said sequence includes at least one phase of charging by injecting a charging current into the cells of this first electrical energy storage module, which is generated by braking of the first electric drive assembly, and at least one phase of maintaining a nonzero setpoint speed for the transport system
 - 15 during said braking, which is applied at least partly to a second electric drive assembly of the system.

[012] With respect to the solution of the prior art, the solution of the invention makes it possible to omit any power connection between two modules so as to avoid the use of a converter to transfer energy from one to the other. Furthermore, the absence of a power
 20 connection allows the modularity of the system to be increased, each module being able to be easily replaced.

[013] According to one particularity of the invention, the processing and management means include a central unit and a plurality of electrical energy management units, each of which is associated with a distinct electrical energy storage module of said at least two
 25 electric drive assemblies.

[014] According to another particularity of the invention, the system includes at least two communication links linking the central unit to each drive assembly.

[015] The solution of the invention will make it possible in particular to transfer energy from one electrical energy storage module to another electrical energy storage module to allow the
 30 module to be charged to a determined state of charge allowing management functions of the module to be implemented. One of the management functions of the module relates in particular to voltage-balancing the cells of the electrical energy storage module. Specifically, it should be noted that while the fully electric solutions afford certain advantages, the electrical energy storage modules used need to be managed appropriately. Specifically, an electrical
 35 energy storage module commonly includes a plurality of elementary electrical energy storage cells connected in series and/or in parallel in order to produce the total power supply capacity and/or voltage. With time and use, and because of imperfections in these elementary cells, differences in state of charge develop between the cells of one and the same electrical energy storage module. If nothing is done to balance the states of charge of the cells of a
 40 module, the electrical energy stored in the module cannot be used in its entirety. Specifically,

the voltage of one cell will limit charging while the voltage of another cell will limit discharging. In other words, the module stops being charged as soon as at least one cell is completely charged and the module is discharged as soon as at least one cell is completely discharged.

The voltage imbalances between cells therefore limit the use of the battery. It is therefore
 5 necessary to voltage-balance the elementary cells of a module regularly in order to maintain optimum performance levels. Various solutions have been proposed for voltage-balancing the cells of a module. One solution, referred to as a passive solution, consists in using dissipation resistors to discharge overcharged cells in a targeted manner. Another solution, referred to as an active solution, consists in charging the cells in a targeted manner until balancing is
 10 achieved.

[016] In either case, the balancing sequence cannot always be carried out while the transport system is in operation. For certain battery technologies, such as lithium-iron-phosphate (LiFePO_4) batteries, the balancing sequence must take place when the transport system is at standstill and upon completion of charging of the module. However, this
 15 balancing sequence is carried out with a small current and is particularly slow, therefore increasing the total duration of charging of a module. One of the solutions would be to remove the modules to be charged from the system and to replace them with pre-charged modules, but this operation is long and difficult to carry out, the modules being particularly heavy and bulky. The solution therefore consists in charging the modules while they are still on the
 20 transport system. By keeping the storage modules on the transport system as they are being charged, a step of replacing the modules to be charged is no longer needed but the time for which the system is available is decreased, since the system must be at standstill, at least for the sequence of balancing the cells of its modules.

[017] Another object of the invention is therefore to provide a solution, using the energy
 25 transfer principle described above, for voltage-balancing the cells of an electrical energy storage module used in a transport system without overly affecting the time for which the transport system is available.

[018] This other object of the invention is achieved by means of the system such as defined above in which said sequence consists of a sequence of voltage-balancing the cells of the
 30 electrical energy storage module.

[019] According to one particularity, the balancing sequence includes a plurality of successive charging phases, involving a plurality of successive injections of charging current into the electrical energy storage module having the cells which are to be balanced, separated from one another by balancing phases.

35 [020] Furthermore, according to another aspect of the invention, each drive assembly includes:

- two electric motors;
- two converters, each of which is intended to control a distinct electric motor;
- an electrical energy storage module.

[021] According to another particularity, each rolling assembly includes two wheels, each of which is actuated by a distinct motor of the drive assembly.

[022] According to another particularity, each drive assembly includes a charger that is incorporated within the electrical energy storage module.

5 [023] According to another particularity, the electrical energy storage module of each drive assembly includes an auxiliary output that is arranged to supply at least one power auxiliary with power.

[024] According to another particularity, this auxiliary output is protected by two diodes.

[025] According to another particularity, each drive assembly includes an electrical energy
10 management unit stored in the electrical energy storage module.

[026] The invention also relates to a method for managing electrical energy in a transport system in accordance with that defined above, said method including the following steps:

- determining a request to run at least one management function within the electrical energy storage module of the first electrical energy assembly;
- 15 - determining a sequence to be applied to the electrical energy storage module of the first electric drive assembly according to said determined management function, said sequence comprising at least one phase of charging by injecting a charging current into the cells of the electrical energy storage module of the first electric drive assembly, which is generated by braking of the first electric drive assembly, and at least one phase of maintaining a nonzero setpoint speed for the transport system during said braking, which is applied at least partly to said second electric drive assembly.

[027] According to one particularity, said sequence consists of a sequence of voltage-balancing the cells of the electrical energy storage module.

25 [028] According to another particularity, the balancing sequence includes a plurality of successive charging phases, involving a plurality of successive injections of charging current into the electrical energy storage module having the cells which are to be balanced, separated from one another by balancing phases.

Brief description of the figures

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[029] Other features and advantages will become apparent in the following detailed description that is provided with reference to the appended drawings, in which:

- figure 1 shows, schematically, a transport system according to the invention;
- figure 2 shows, schematically, a vehicle employed in a transport system according to the invention;
- 35 - figure 3 shows, schematically, a drive assembly employed in the transport system of the invention;
- figure 4 shows, schematically, one variant embodiment of the drive assembly shown in figure 3;

- figure 5 shows the power supply circuit for an auxiliary, produced using the storage modules employed in the drive assemblies as shown in figure 4;
- figure 6 shows, schematically, an operating principle of the transport system of the invention;
- 5 - figures 7A and 7B show a plurality of curves illustrating the operating principle presented in figure 6;
- figure 8 shows an algorithm run in order to implement the operating principle presented in figure 6;

Detailed description of at least one embodiment

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[030] The invention relates to an electrically powered transport system, i.e. one drawn entirely by electrical power delivered by batteries. The invention is more particularly applicable to a transport system 1 of the type of a train of vehicles, used in particular to transport loads in the construction of infrastructure, such as for example tunnels. Such a

15 system 1 is shown in figure 1.

[031] Below, in general, for the various elements of the system, the following references will be used:

- Ei_X for the drive assemblies;
- Mi_X for the electrical energy storage modules;
- 20 - U_Mi_X for the electrical energy management units of each electrical energy storage module;
- MOTi_Y for the electric motors;
- CONVi_Y for the converters;
- Ri_X for the rolling assemblies;
- 25 - Ri_Y for the wheels;

where X=1 or 2 and Y=10, 11, 20 or 21.

[032] This type of system 1 includes rolling means, such as wheels cooperating with rails or with the ground directly.

[033] Nonlimitingly, the system is considered to include a number n of vehicles Vi, where i ranges from 1 to n and n is greater than or equal to 1. The vehicles are coupled to one another by means of a mechanical connection.

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[034] The system is for example a two-cab system, i.e. it includes a first driver cab in the top vehicle (V1 in figure 1) and a second driver cab in the tail vehicle (V3 in figure 1). This solution allows the system to travel in one direction or the other without turning around, which

35 is advantageous when constructing infrastructure such as a tunnel.

[035] Throughout the rest of the description, with reference to figure 2, nonlimitingly, each vehicle Vi of the system is considered to include a chassis 30 and at least two rolling assemblies Ri_1, Ri_2, allowing the vehicle to roll. Each rolling assembly Ri_1, Ri_2 advantageously includes two wheels (referenced Ri_10, Ri_11 for the first rolling assembly and Ri_20, Ri_21 for the second rolling assembly) which are connected to one another by an

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axle 10, 20. The system thus includes $2n$ rolling assemblies Ri_1 , Ri_2 , where i ranges from 1 to n and n is greater than or equal to 1. Each axle may have a directional function allowing the vehicle Vi to be oriented appropriately on its travel.

[036] According to one aspect of the invention, in each vehicle Vi , each rolling assembly
5 Ri_1 , Ri_2 is driven in rotation by a distinct electric drive assembly Ei_1 , Ei_2 . The system thus includes $2n$ drive assemblies, n being greater than or equal to 1.

[037] According to the invention, each drive assembly includes:

- at least one electric motor for driving the rolling assembly in rotation;
- at least one voltage converter for controlling each electric motor;
- 10 - an electrical energy storage module.

[038] Nonlimitingly but advantageously, with reference to figures 2 to 4, each drive assembly will include:

- two electric motors ($MOTi_10$, $MOTi_11$ for the drive assembly Ei_1 and $MOTi_20$, $MOTi_21$ for the drive assembly Ei_2), a distinct electric motor being
15 associated with each wheel of the rolling assembly;
- two distinct converters ($CONVi_10$, $CONVi_11$ and $CONVi_20$, $CONVi_21$), each of which is intended to control a distinct motor of the drive assembly;
- an electrical energy storage module Mi_1 , Mi_2 for supplying the two electric motors of the assembly with power.

20 [039] The drive assemblies are advantageously all identical.

[040] The motors of one and the same drive assembly are advantageously all identical.

[041] The converters of one and the same drive assembly are advantageously all identical.

[042] The electrical energy storage modules of one and the same drive assembly are advantageously all identical.

25 [043] Conventionally, the electrical energy storage modules of the system are recharged using a charging point. The charging point will in particular be able to include means for managing the charging of the electrical energy storage modules of the system.

[044] Figures 3 and 4 show, in detail, a drive assembly Ei_1 of a vehicle Vi according to two distinct variant embodiments. These particularities are advantageously applicable to any drive
30 assembly of the system.

[045] According to the invention, in the drive assembly Ei_1 , each voltage converter $CONVi_10$, $CONVi_11$ is a bidirectional converter, i.e. current-reversible, thus allowing operation:

- in a motor mode, in which it controls a transfer of electrical energy from the
35 electrical energy storage module to its motor in order to supply it with power; or
- in a generator mode, in which it controls a transfer of electrical energy from its electric motor to the electrical energy storage module. This generator mode is used when the electric motor is braked.

[046] As is known, such a converter will include for example:

- an output stage (DC-to-AC converter) including a plurality of switching arms controlled by a control unit;
- a plurality of output phases connected to the electric motor and to which the output voltages for controlling the electric motor are applied.

5 [047] In the drive assembly Ei_1, each converter CONVi_10, CONVi_11 will advantageously be positioned as close as possible to the motor that it controls, in order to limit cable lengths and decrease interference as far as possible.

[048] As is known, the control unit of the converter implements at least one converter control loop to control the transfers of energy from the electrical energy storage module to the electric
10 motor in order to run it at a setpoint speed or from the electric motor to the electrical energy storage module in order to instigate the charging of the electrical energy storage module.

[049] As is known, when the electric motor is braked, if the rolling assembly drives the electric motor, the electrical energy generated by this driving action may be recovered and transferred to the electrical energy storage module.

15 [050] In one and the same drive assembly, in motor mode, the two converters are advantageously controlled using the same setpoint such that both motors run at the same speed.

[051] According to one aspect of the invention, an electrical energy storage module Mi_1 will be considered to include a plurality of elementary electrical energy storage cells C_Mi_1.

20 The elementary cells C_Mi_1 may be grouped into a plurality of groups of cells connected in series, the cells of one and the same group being connected to one another in series and/or in parallel. Throughout the rest of the description, the term "cell" will be used to refer both to one cell and to a group of cells. Each energy storage module takes the form, for example, of an independent housing enclosing the electrical energy storage cells. Each module Mi_1 is
25 preferably transportable and removable from the system so as to be easily replaced.

[052] Nonlimitingly, in each module, the storage cells will for example be LiFePO₄-type cells. Each cell of this type will for example have a voltage that may range from 2.5 V to 3.5 V, with a nominal voltage of 3.2 V. They may have a capacity ranging from 1 Ah to 200 Ah depending on the manufacturer. A storage module includes for example a plurality of packs of cells
30 connected in series allowing a high nominal operating voltage to be obtained.

[053] With reference to figures 3 and 4, the drive assembly Ei_1 advantageously includes its own charger Ch_Mi_1 that is arranged to convert the AC voltage delivered by an electrical power source into a DC voltage. Such a charger Ch_Mi_1 is advantageously incorporated within the electrical energy storage module Mi_1 and includes an AC-to-DC converter. This is
35 used to recharge the cells of each electrical energy storage module with electrical energy.

[054] The module Mi_1 includes a DC power supply bus to which each converter CONVi_10, CONVi_11 of the drive assembly and the electrical energy storage cells C_Mi_1 of the module are all connected. A bus capacitor is for example used to stabilize the voltage of the DC bus of the module.

[055] The module will advantageously include devices for actively or passively discharging its electrical energy storage cells. One passive solution will consist for example in using discharge resistors allowing the cells of the module to be discharged by electrical dissipation.

[056] The drive assembly Ei_1 advantageously includes means for managing the electrical energy stored in the cells of its module.

[057] These electrical energy management means include for example voltage sensors associated with each cell of the module and intended to measure the voltage across the terminals of each cell of the module. They also include means for acquiring the measured voltage data, means for determining the state of charge (SOC) of each cell of the module and means for determining the state of health (SOH) of the module. They advantageously include means for determining requests to run one or more management functions of the module. The acquisition means, the means for determining the state of charge and the means for determining the requests to run the management functions are for example grouped into one and the same electrical energy management unit U_MI_1 (for example such as a BMS, for battery management system), taking the form, for example, of a distinct microcontroller associated with the management of each electrical energy storage module. This management unit is for example housed in the same housing as the cells of the module.

[058] Nonlimitingly, with reference to figure 4, the electrical energy storage module Mi_1 may include a specific output AUX2_Mi_1, with two terminals, for supplying power auxiliaries, for example specific tools (for example a concrete mixer), with power. This specific auxiliary output is advantageously protected by two diodes making it possible to prevent any transfer of current from one storage module to another when at least two modules are connected in parallel and two contactors making it possible to control the delivery of electrical energy from the module to the power auxiliaries.

[059] Figure 5 illustrates the electrical connection architecture between an auxiliary consumer AUX and a plurality of storage modules (M1_1, M1_2, M2_1, M2_2 for example) connected in parallel. This figure elucidates the advantage of the presence of the diodes mentioned above. The auxiliary AUX is connected in parallel to the specific output of each electrical energy storage module. Naturally, it is the module with the highest voltage (i.e. the least discharged module) which delivers the power to the connected auxiliary.

[060] The diodes are positioned so as to prevent any current flowing back to the modules, i.e. any regeneration current from the auxiliary, and any exchange of current from one module to the next.

[061] In the module Mi_1, a plurality of contactors are for example positioned suitably in order to select the output of the module, between the main output connected to the motors of the drive assembly and the auxiliary output mentioned above. These contactors are for example controlled by the electrical energy management unit of the module.

[062] In figures 3 and 4, it is possible to see that each module advantageously incorporates another, low-voltage (for example 24 V) auxiliary output AUX1_Mi_1 via a DC-to-DC converter which is connected to the DC power supply bus of the module.

[063] With reference to figure 6, the system 1 further includes a central control unit UC for controlling the $2n$ electric drive assemblies of the transport system 1. Figure 6 shows the functional relationships between the central unit and any two drive assemblies of the transport system. Nonlimitingly, figure 6 thus shows the two drive assemblies Ei_1 and Ei_2, but it should be understood that the architecture applies to all of the assemblies of the system. The central unit UC takes the form, for example, of a microcontroller including a plurality of inputs and a plurality of outputs.

[064] Each electric drive assembly Ei_1 (Ei_2) is connected to inputs or outputs of the central unit UC by various communication links:

- 10 - a first communication link L1_Ei_1 (L1_Ei_2) between the central unit UC and the control units of the converters of the electric drive assembly. Via this first link, the central unit UC transmits a speed command ($V_{ref_Ei_1}$, $V_{ref_Ei_2}$) to each control unit for controlling the converter and hence the electric motor of the drive assembly;
- 15 - a second communication link L2_Ei_1 (L2_Ei_2) between the central unit UC and the electrical energy management unit U_Mi_1, (U_Mi_2) of the electrical energy storage module of the drive assembly. Through this second communication link, the central unit UC may in particular receive, from the electrical energy management unit, a request to charge while the system is in operation in order to
- 20 implement a determined management function of the electrical energy storage module.

[065] According to one particularity of the invention, the electrical energy storage modules Mi_X used to supply the motors of the transport system with electrical energy have no electrical power connection between them, nor any power transfer means (converter, contactors, etc.) allowing power to be transferred directly from one module to another module via an electrical power connection. Each one is therefore dedicated to driving one or both electric motors of their electric drive assembly and they share no common DC bus.

[066] One of the principles of the invention consists in allowing certain management functions within each electrical energy storage module Mi_X to be implemented while the transport system 1 is in operation, i.e. rolling. Nonlimitingly, these management functions are for example the following:

- voltage-balancing the cells of the electrical energy storage module Mi_X;
- reaching a determined state of charge of the electrical energy storage module Mi_X, for example for supplying an auxiliary with power;
- 35 - reaching a determined state of charge for a test phase or for being positioned in a relevant zone of the discharge curve of the module.

[067] In this last case, it is a matter for example reaching a determined state of charge corresponding to a relevant zone of the discharge curve (voltage curve according to the state of charge) of the electrical energy storage module Mi_X. Depending on the technology used to produce the cells of a module, the discharge curve of the module may vary. Specifically,

certain discharge curves exhibit voltage plateaus at which it is difficult to discern the state of charge of the various storage cells of the module. It may therefore make sense to be positioned in a relevant zone of the curve so as to better manage the state of the various cells.

5 [068] Nonlimitingly, each management function will be able to be implemented in each electrical energy storage module Mi_X independently. The central unit UC and the electrical energy management units U_Mi_X of each electrical energy storage module are thus capable of :

- 10 - determining a request to run a management function of an electrical energy storage module;
- determining the sequence to be applied in order to implement said selected management function;

[069] The run request will advantageously be determined by each electrical energy management unit U_Mi_X associated with the electrical energy storage modules. This will
15 involve for example measuring the voltage across the terminals of the cells of the electrical energy storage module Mi_X . After having acquired the measured voltage data, a software module of the electrical energy management unit U_Mi_X is then capable of processing said data and of determining whether a management function must be run for the associated electrical energy storage module. A run request may subsequently be transmitted to the
20 central unit UC through the second communication link described above.

[070] The sequence to be applied to an electrical energy storage module Mi_X will advantageously be determined by a software processing module of the central unit UC. Advantageously, the sequence to be applied then includes at least the following two particularities:

- 25 - at least one phase Ph_ch of charging the electrical energy storage module Mi_X by controlling its electric drive assembly Ei_X in braking mode;
- a phase of maintaining a nonzero overall setpoint speed for the transport system 1, in order to allow said braking.

[071] In general, it should be understood that the running of a management function on an
30 electrical energy storage module Mi_X may be applied to any module Mi_X of an electric drive assembly Ei_X of the system regardless of the vehicle Vi with which each one is associated and that the maintaining of the nonzero setpoint speed $Vref$ is applicable to one or more of the other drive assemblies of the system, regardless of the vehicles of the system with which they are associated. Similarly, it should also be understood that management
35 functions may be run for all of the modules at the same time, except for at least one module which must be used to draw the system.

[072] One of the implemented management functions consists in particular in balancing the cells of an electrical energy storage module while the transport system 1 is in operation. To achieve this, the central unit UC must manage the balancing requests from each electrical
40 energy management unit while meeting the overall speed setpoint $Vref$ requested by the

system 1. The implementation of the invention therefore assumes that the transport system 1 includes at least two distinct drive assemblies, at least one first assembly operating in motor mode in order to drive the transport system at a nonzero setpoint speed and consuming the electrical energy available in its storage module and at least one second drive assembly
 5 controlled in braking mode in order to recover current intended for running the balancing sequence. This principle may be applied for any management function of a module.

[073] Nonlimitingly, for a module Mi_1 , a balancing request received by the central unit UC is processed in the manner described below, in conjunction with figure 8.

[074] Step E1: the central unit UC receives for example a request to balance the cells of the
 10 electrical energy storage module Mi_1 of the first drive assembly Ei_1 from the electrical energy management unit associated with this electrical energy storage module.

[075] Step E2: the central unit UC checks whether the balancing request may be processed. For this, the central unit UC determines whether the electrical power required to drive the system at the setpoint speed V_{ref} still remains available even in the absence of that of the
 15 storage module Mi_1 with the cells to be balanced.

[076] Step E3: if the required electrical power still remains available, the central unit UC issues a positive response to the request to balance the cells of the electrical energy storage module Mi_1 .

[077] Step E4: a voltage-balancing sequence is carried out by alternating phases of
 20 charging the cells of the module with phases of balancing the voltages of the cells of the module. Each charging phase is implemented by a braking-mode command sent to the converters $CONVi_10$, $CONVi_11$ of the first drive assembly Ei_1 . The braking is driven by the converters. The braking is torque- (and hence current-) and duration-/repetition-controlled. It may therefore be matched to the commands from the central unit UC in order to carry out
 25 the phases of charging the cells of the electrical energy storage module. Since the overall setpoint speed V_{ref} is for example kept constant (nonzero) for the duration of the balancing sequence, each other electric motor of the system generates enough torque to maintain this overall setpoint speed V_{ref} .

[078] Step E3': If the electrical power required to drive the system 1 at the setpoint speed
 30 V_{ref} is not available to meet the balancing request, the central unit UC puts the balancing request on hold and will restart the test later.

[079] The electric current generated when the electric motors $MOTi_10$, $MOTi_11$ are decelerated is injected into the electrical energy storage module Mi_1 and used to charge the cells of the module before a phase of voltage-balancing the cells of this module.

[080] It will be seen below that several injections of charging current, hence several successive braking phases, are advantageously carried out in one and the same sequence of voltage-balancing the cells of the module.

[081] The sequence of voltage-balancing the cells of the module Mi_1 is preferably managed by the electrical energy management unit of the electrical energy storage module
 40 U_Mi_1 .

[082] It should be noted that the current required to recharge the cells of the module during balancing is small and is negligible with respect to the current required to draw the system 1. The energy required for balancing is also very low with respect to that required for traction, less than 1%, for example of the order of 0.1%. However, it should be understood that it is
 5 entirely possible for the power drawn over a charging phase to be relatively high, around 10%.

[083] Furthermore, the energy storage module Mi_1 being balanced obviously cannot be used to drive the vehicle and the system. Of course, the setpoint speed V_{ref} applied to the transport system may vary over the balancing sequence. Thus, when its energy or its power
 10 is required by the system, the balancing sequence will have to be interrupted.

[084] Figures 7A and 7B illustrate, by means of curves, the principle of a sequence of voltage-balancing the cells of an electrical energy storage module Mi_1 . Figure 7A shows a balancing sequence in its entirety while figure 7B is a close-up of the balancing sequence in order to allow its principle to be grasped better. In figure 7A, it is thus possible to see that :

- 15 - the sequence of balancing the voltages across the terminals of each cell of the storage module Mi_1 is carried out by alternating several successive phases (Ph_ch) of charging the cells of a module with current with phases (Pch_eq) of voltage-balancing the cells of this module. In each charging phase, the charging current I_{mod} is generated by the braking of the electric motors associated with
 20 the storage module with the cells that are to be balanced;
- in each charging phase (Ph_ch), the current I_{mod} that flows through the module increases and forms a current spike. Each current I_{mod} spike corresponds to a charging phase (Ph_ch); the voltage U_{mod} corresponds to the voltage of the electrical energy storage module;
- 25 - the state of charge (SOC) of the module increases stepwise successively until actually reaching 100% at the end of the balancing sequence;
- the highest voltage curve U_{cell_max} of one cell of the module and the lowest voltage curve U_{cell_min} of another cell of the module converge toward a common value of around 3.75 V at the end of the balancing sequence.

30 [085] In figure 7B, it is possible to see in greater detail that:

- at time t_1 , the sequence of voltage-balancing the cells of the module Mi_1 begins with a first phase of charging the cells of the module Mi_1 ; the electrical energy management unit U_{Mi_1} of the module Mi_1 transmits a braking-mode request to the central unit UC in order to obtain a current for charging the cells of its
 35 module Mi_1 via regenerative braking;
- between time t_1 and time t_2 , the first charging phase results in a first positive variation in the charging current I_{mod} . This variation in current results in an increase in the voltage across the terminals of each cell of the module (the figure shows the highest voltage curve U_{cell_max} of one cell of the module and the
 40 lowest voltage curve U_{cell_min} of another cell of the module). The voltage U_{mod}

across the terminals of the module also increases; the duration of the charging phase Ph_ch is managed by the electrical energy management unit U_Mi_1 of the module Mi_1;

- at time t2, a first charging phase ends;
- 5 - between time t2 and time t3, the electric motor is controlled in freewheeling mode, so that it does not operate in motor mode or in generator mode; the electrical energy management unit U_Mi_1 implements a balancing phase. The cells which are overcharged are thus discharged by dissipation in the discharge resistors;
- 10 - between time t3 and time t4, the management unit U_Mi_1 controls a second charging phase, resulting in a second positive variation in the charging current I_{mod} of the module; the duration of the second charging phase is managed by the electrical energy management unit U_Mi_1 of the module Mi_1;
- 15 - at time t4, the second charging phase ends;
- 15 - between time t4 and time t5, the electrical energy management unit U_Mi_1 of the module Mi_1 controls a new phase of balancing its cells.
- 20 - the alternation between charging phases and balancing phases is advantageously implemented several times (potentially more than twice) until the cells of the electrical energy storage module are voltage-balanced, i.e. until each cell is in a satisfactory state of charge (see figure 7A);

[086] In figures 7A and 7B, it is possible to see that each injection of a charging current by braking is carried out over a short duration with respect to the total duration of the sequence of voltage-balancing the cells. However, it should be understood that the durations of each charging phase and of each balancing phase might be dependent on several parameters, in particular on the type of cells to be charged, on the design of the discharge devices (resistors), on the charging current, on the voltage imbalance of the cells, etc.

[087] As described above, between two injections by braking, the motor is for example in freewheeling mode in the balancing phase. The voltage of each cell of the module decreases by relaxation and potentially, in addition, in a controlled manner, through passive or active discharge. For example, discharge resistors form part of the storage module, one discharge resistor being associated with each cell or group of cells of the module.

[088] The balancing sequence is implemented by the electrical management unit of the module Mi_1 by running software modules, more particularly a software module for controlling the charging for each charging phase Ph_ch and a balancing software module for controlling the voltage balancing in each balancing phase Ph_eq of the sequence. The electrical management unit U_Mi_1 receives, in particular at regular intervals, the voltage levels of the various cells of the module in order to adjust the charging with current by braking and the discharging of the cells through the discharge resistors until the cells of the module are voltage-balanced. Voltage sensors are therefore used to measure the voltage across the terminals of each cell of the module.

[089] Advantageously, the electrical management unit U_Mi_1 of the module determines when it considers all of the cells of its module to be voltage-balanced. The balancing sequence may thus be of variable duration.

[090] Nonlimitingly, switches (for example MOSFETs) controlled by the electrical
5 management unit of the module are advantageously used to control the targeted discharging of the various cells through the discharge resistors.

[091] In the above description, it is understood that it is advantageous to provide a solution for electrical energy management in a transport system. The proposed solution makes it possible to implement management functions, such as for example a sequence of balancing
10 the cells of a module, while the transport system is in operation. The solution of the invention is therefore particularly advantageous since it makes it possible to avoid keeping the transport system at standstill for too long.

CLAIMS

1. An electrically powered transport system (1) including:

- a plurality of rolling assemblies (Ri_X);
- 5 - a plurality of electric drive assemblies (Ei_X), each of which is associated with a distinct rolling assembly, each electric drive assembly comprising:
 - at least one electric motor (MOTi_Y) for driving said assembly for rolling on the ground in rotation;
 - at least one electrical energy storage module (Mi_X) that is intended to supply said electric motor with electrical energy and that includes a plurality of electrical energy storage cells;
 - 10 ○ at least one bidirectional voltage converter (CONVi_Y) that is arranged to control a transfer of electrical energy between said electrical energy storage module and said electric motor in a motor mode or a transfer of energy from the electric motor to the electrical energy storage module in a generator mode;
 - 15 - the electrical energy storage module of each electric drive assembly having no electrical power connection with the electrical energy storage module of each other electric drive assembly;
 - 20 - processing and management means that are arranged to manage each electrical energy storage module and to control each converter of said electric drive assemblies, characterized in that the processing and management means include:
 - means for determining a request to run at least one management function within each electrical energy storage module;
 - 25 ○ means for determining a sequence to be applied to the electrical energy storage module according to said management function determined for this module; and in that
 - for a first module (Mi_1) of a first electric drive assembly (Ei_1) of the system, said sequence includes at least one phase of charging by injecting a charging current into the cells of this first electrical energy storage module, which is generated by braking of the first electric drive assembly (Ei_1), and at least one phase of maintaining a nonzero setpoint speed for the transport system during said braking, which is applied at least partly to a second electric drive assembly (Ei_2) of the system.
 - 30 35

2. The system as claimed in claim 1, characterized in that the processing and management means include a central unit (UC) and a plurality of electrical energy management units

(U_Mi_X), each of which is associated with a distinct electrical energy storage module of said at least two electric drive assemblies.

3. The system as claimed in claim 2, characterized in that it includes at least two
5 communication links linking the central unit to each drive assembly.

4. The system as claimed in one of claims 1 to 3, characterized in that said sequence consists of a sequence of voltage-balancing the cells of the electrical energy storage module.

10 5. The system as claimed in claim 4, characterized in that the balancing sequence includes a plurality of successive charging phases (Ph_ch), involving a plurality of successive injections of charging current into the electrical energy storage module having the cells which are to be balanced, separated from one another by balancing phases (Ph_eq).

15 6. The system as claimed in one of claims 1 to 5, characterized in that each drive assembly (Ei_X) includes:

- two electric motors (MOTi_Y);
two converters (CONVi_Y), each of which is intended to control a distinct electric motor;
- 20 - an electrical energy storage module (Mi_X).

7. The system as claimed in claim 6, characterized in that each rolling assembly (Ri_X) includes two wheels (Ri_Z), each of which is actuated by a distinct motor (MOTi_Y) of the drive assembly (Ei_X).

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8. The system as claimed in claim 6 or 7, characterized in that each drive assembly includes a charger that is incorporated within the electrical energy storage module.

9. The system as claimed in one of claims 1 to 8, characterized in that the electrical energy
30 storage module (Mi_X) of each drive assembly includes an auxiliary output that is arranged to supply at least one power auxiliary with power.

10. The system as claimed in claim 9, characterized in that the auxiliary output is protected by two diodes.

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11. The system as claimed in one of claims 1 to 10, characterized in that each drive assembly (Ei_X) includes an electrical energy management unit (U_Mi_X) stored in the electrical energy storage module (Mi_X).

12. A method for managing electrical energy in a transport system in accordance with that defined in claims 1 to 11, characterized in that it includes the following steps:

- determining a request to run at least one management function within the electrical energy storage module of the first electrical energy assembly;
- 5 - determining a sequence to be applied to the electrical energy storage module of the first electric drive assembly according to said determined management function, said sequence comprising at least one phase (Ph_ch) of charging by injecting a charging current into the cells of the electrical energy storage module of the first electric drive assembly, which is generated by braking of the first
- 10 electric drive assembly, and at least one phase of maintaining a nonzero setpoint speed for the transport system during said braking, which is applied at least partly to said second electric drive assembly.

13. The method as claimed in claim 12, characterized in that said sequence consists of a
15 sequence of voltage-balancing the cells of the electrical energy storage module.

14. The method as claimed in claim 13, characterized in that the balancing sequence includes a plurality of successive charging phases (Ph_ch), involving a plurality of successive injections of charging current into the electrical energy storage module having the cells which
20 are to be balanced, separated from one another by balancing phases (Ph_eq).