

METHOD AND SYSTEM FOR MANAGING THE CHARGING OF MODULES FOR STORING ELECTRICAL POWER, SAID MODULES BEING EMPLOYED IN AN ELECTRICALLY POWERED TRANSPORT SYSTEM

5 Technical field of the invention

[001] The present invention relates to a method for managing the charging of an electrical energy storage module employed in particular in an electrically powered transport system and to a system for managing the electrical charging of an electrical energy storage module employed in the electrically powered transport system.

Prior art

[002] Nowadays, various solutions for driving a transport system are recognized. A first, 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.

[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, 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 system composed of a train of a plurality of vehicles that are coupled to one another and include a top vehicle and a tail 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 power.

[005] While the fully electric solutions afford certain advantages, the electrical energy storage modules used need to be managed appropriately.

[006] An electrical 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. An example of a management operation to be performed on a module consists in checking, from time to time, that these cells are balanced in terms of voltage. Specifically, with time and use, and because of imperfections in the cells of the module, differences in state of charge develop between the cells. If nothing is done to balance the states of charge of the cells of a 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 until at least one cell is completely discharged. The voltage imbalances between cells therefore limit the use of the battery. It is therefore necessary to voltage-balance the elementary cells of a module regularly in order to maintain optimum performance levels.

[007] For certain battery technologies, such as lithium-iron-phosphate (LiFePO_4) batteries, the voltage balancing must take place when the transport system is at standstill and upon completion of charging of the module. However, this balancing sequence is carried out with a small current and is particularly slow, therefore increasing the total duration of charging of a module.

[008] Furthermore, current solutions allow the recovery of electrical energy by the storage modules through regenerative braking of the transport system. However, such a solution can be implemented only if the storage module is not completely charged.

[009] Document **US2015/0251648A1**, meanwhile, describes a solution for controlling a hybrid vehicle. This solution is applicable in particular for a system with one vehicle or a plurality of vehicles connected to one another. A central control unit allows commands (P_{e_ref} and P_{c_ref}) to be generated for a combustion engine and for a monitoring unit that is intended to control a converter, respectively.

[010] The battery is charged either by the power delivered by the generator to which the combustion engine is connected or by power derived from braking the electric motor. The central control unit determines in particular a target state of charge (SOC_{ref}) on the basis of journey profile data defined in the "Elevation map" block. The central control unit next runs an algorithm to determine whether to start up the combustion engine to charge the battery or otherwise, taking into account the current state of charge of the battery and the target state of charge for making the journey.

[011] This solution of the prior art does not aim to manage the charging of a plurality of modules included in different drive assemblies used in one and the same transport system. It aims to manage the operation of a single drive assembly, this drive assembly comprising a battery, an electric motor and a combustion engine allowing the battery to be recharged when the state of charge of the battery is deemed to be insufficient for making the envisaged journey.

[012] There is therefore a need for suitable management of the charging of a plurality of storage modules of a transport system so as to make it possible to benefit from energy recovery solutions while also addressing the need to implement certain management functions on each module, such as for example a function for voltage-balancing the cells of the module.

[013] The object of the invention is therefore to provide a solution that addresses this need.

Summary of the invention

[014] This object is achieved by a method for managing the electrical charging of a plurality of electrical energy storage modules that are used in an electrically powered transport system that is intended to make a journey, said transport system including:

- at least two rolling assemblies;
- at least two electric drive assemblies, referred to as the first electric drive assembly and the second electric drive assembly, each of which is associated with a distinct rolling assembly, each electric drive assembly comprising:
 - o at least one electric motor for driving said rolling assembly over the ground;
 - o at least one electrical energy storage module that is intended to supply said electric motor with electrical power and that includes a plurality of electrical energy storage cells;
 - o at least one bidirectional voltage converter that is arranged to control the transfer of electrical energy between said electrical energy storage module and said electric motor;
- the electrical energy storage module of the first electric drive assembly having no electrical power connection with the electrical energy storage module of the second electric drive assembly;

said method comprising:

- a step of determining a target state of charge to be reached so as to be able to make said journey completely electrically autonomously and accounting for an electrical demand for charging and discharging the electrical energy storage modules resulting from the operation of the transport system over said journey;
- a step of determining, for each storage module of the transport system, a state of charge to be reached, this state of charge being determined for each module according to:
 - o the determined target state of charge;

o the implementation of one or more management functions on the electrical energy storage module of the system.

[015] According to one particularity, the state of charge is also determined by accounting for a state of availability that is assigned to the electrical energy storage module over the journey.

[016] According to another particularity, the state of charge to be reached for at least one storage module corresponds to an optimal state of charge which is calculated from:

- the determined overall target state of charge;
- a number of modules to be charged to a particular state of charge according to said implemented management function and the state of charge that is assigned to these modules;
- the total number of modules of the system.

[017] According to another particularity, said optimal state of charge is also determined by accounting for a number of modules that are isolated, i.e. that do not participate in charging or in driving said transport system.

[018] According to another particularity of the invention, one management function consists of a sequence of voltage-balancing the cells of an electrical energy storage module.

[019] According to another particularity, the method includes:

- a test step for determining whether a sequence of voltage-balancing the cells of said electrical module is required;
- a step of controlling an operation of charging the electrical energy storage module to said determined optimal state of charge, if said voltage-balancing sequence does not have to be implemented;
- a step of controlling an operation of charging the electrical energy storage module until a second state of charge that is equal to 100% is reached and a sequence of voltage-balancing the cells once this second state of charge has been reached if said balancing sequence is required and accepted.

[020] According to another particularity, the test step is implemented on the basis of at least one stored decision criterion having a determined value.

[021] According to another particularity, the test step includes a step of measuring the voltage across the terminals of the electrical energy storage cells of the electrical energy storage module.

[022] According to another particularity, the method includes a step of checking a state of progress of the sequence of voltage-balancing the cells of the electrical energy storage module.

[023] According to another particularity, the method includes a step of holding the decision criterion at its determined value for as long as the balancing sequence is yet to be completed.

[024] According to another particularity, the method includes a step of modifying said value of the decision criterion, implemented after the end of the sequence of voltage-balancing the cells of the electrical energy storage module.

[025] The invention also relates to a system for managing the electrical charging of a plurality of electrical energy storage modules that are used in an electrically powered transport system that is intended to make a journey, said transport system including:

- at least two rolling assemblies;
- at least two electric drive assemblies, referred to as the first electric drive assembly and the second electric drive assembly, each of which is associated with a distinct rolling assembly, each electric drive assembly comprising:
 - o at least one electric motor for driving said rolling assembly over the ground;
 - o at least one electrical energy storage module that is intended to supply said electric motor with electrical power and that includes a plurality of electrical energy storage cells;
 - o at least one bidirectional voltage converter that is arranged to control the transfer of electrical energy between said electrical energy storage module and said electric motor;
- the electrical energy storage module of the first electric drive assembly having no electrical power connection with the electrical energy storage module of the second electric drive assembly;
- said management system comprising processing means that are arranged so as to determine an electrical state of charge to be applied to each electrical energy storage module, said processing means comprising:
 - a block for determining a target state of charge to be reached so as to be able to make said journey completely electrically autonomously and accounting for an electrical demand for charging and discharging the modules resulting from the operation of the transport system over said journey;
 - a block for determining, for each storage module of the transport system, a state of charge to be reached, this state of charge being determined for each module according to:
 - o the determined target state of charge;

o the implementation of one or more management functions on the electrical energy storage module of the system.

[026] According to one particularity, the state of charge to be reached for each module is determined by accounting for a state of availability that is assigned to the electrical energy storage module over the journey.

[027] According to another particularity, the state of charge to be reached for at least one storage module corresponds to an optimal state of charge which is calculated from:

- the determined overall target state of charge;
- a number of modules to be charged to a particular state of charge according to said implemented management function and the state of charge that is assigned to these modules;
- the total number of modules of the system.

[028] According to another particularity, said optimal state of charge is also determined by accounting for a number of modules that are isolated, i.e. that do not participate in charging or in driving said transport system.

[029] According to another particularity of the invention, one management function consists of a sequence of voltage-balancing the cells of an electrical energy storage module.

[030] According to another particularity, the system includes:

- a test block that is arranged so as to determine whether an operation of implementing a sequence of voltage-balancing the cells of said electrical module is required;
- a block for controlling a charging operation until said determined optimal state of charge is reached, if said voltage-balancing sequence does not have to be implemented;
- a block for controlling a charging operation until a second state of charge that is equal to 100% is reached and a sequence of voltage-balancing the cells once this second state of charge has been reached if the balancing sequence is required and accepted.

[031] According to another particularity, the test block is run on the basis of at least one stored decision criterion having a determined value.

[032] According to another particularity, the system includes means for measuring the voltage across the terminals of the electrical energy storage cells of the electrical energy storage module and in that said decision criterion is based on voltage measurements made by said measurement means.

[033] According to another particularity, the system includes a test block that is arranged so as to determine the state of progress of the sequence of voltage-balancing the cells of the electrical energy storage module.

[034] According to another particularity, the system includes a block for modifying said value of the decision criterion, run after the end of the sequence of voltage-balancing the cells of the electrical energy storage module.

5 Brief description of the figures

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

- 10 - figure 1 shows, schematically, a transport system such as employed in the context of the invention;
- figure 2 shows, schematically, a vehicle employed in said transport system;
- figure 3 shows, schematically, a drive assembly employed in a transport system;
- 15 - 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;
- 20 - figure 6 shows, schematically, one possible architecture employed in a transport system;
- figure 7 illustrates a case of a transport system application;
- figure 8 schematically illustrates the charge management principle, applied to the electrical energy storage modules of a transport system;
- 25 - figure 9 is a flowchart schematically illustrating a charge management method employed in the invention.

Detailed description of at least one embodiment

30 [036] The invention is in particular used in the field of electrically powered transport systems, i.e. those driven entirely by electrical power delivered by batteries. The invention applies more particularly to the method and system for managing the charging of the electrical energy storage modules that are used to drive such a transport system 1.

35 [037] Nonlimitingly, what will be considered is a transport system 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 system 1 is shown in figure 1.

[038] Below, in general, for the various elements of the transport system 1, the following references will be used:

- 40 - Ei_X for the drive assemblies;

- Mi_X for the electrical energy storage modules;
- U_Mi_X for the electrical energy management units;
- $MOTi_Y$ for the electric motors;
- $CONVi_Y$ for the converters;
- 5 - Ri_X for the rolling assemblies;
- Ri_Y for the wheels;

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

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

10 [040] 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.

[041] 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 is required when constructing infrastructure such as a tunnel.

15 [042] Throughout the rest of the description, with reference to figure 2, nonlimitingly, each vehicle Vi of the system includes 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 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.

25 [043] According to one aspect of the invention, in each vehicle Vi , each rolling assembly Ri_1, Ri_2 is driven 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.

[044] Nonlimitingly, each drive assembly includes:

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

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

- 35 - 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 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;
- 40

- an electrical energy storage module Mi_1 , Mi_2 for supplying the two electric motors of the assembly with power.

[046] The drive assemblies are advantageously all identical.

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

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

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

10 [050] 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 assembly of the system.

[051] Nonlimitingly, in the drive assembly Ei_1 , each voltage converter $CONVi_10$, $CONVi_11$ is advantageously a bidirectional converter, i.e. current-reversible, thus
15 allowing operation:

- in a motor mode, in which it controls a transfer of electrical energy from the electrical energy storage module to its motor in order to supply it with power; or

20 - 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.

[052] 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;

25 - a plurality of output phases connected to the electric motor and to which the output voltages for controlling the electric motor are applied.

[053] 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.

30 [054] 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 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.

35 [055] 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.

[056] 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
40 same speed.

[057] An electrical energy storage module Mi_1 will be considered to include a plurality of elementary electrical energy storage cells C_Mi_1 . 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 preferably transportable and removable from the system so as to be easily replaced.

[058] Nonlimitingly, in each module, the storage cells will for example be $LiFePO_4$ 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 connected in series allowing a high nominal operating voltage to be obtained.

[059] 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 used to recharge the cells of each electrical energy storage module with electrical energy.

[060] 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.

[061] The module will advantageously include a plurality of active or passive discharge devices, allowing the cells of the module to be discharged.

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

[063] 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 a request to voltage-balance the cells of the module. The acquisition means, the means for determining the state of charge and the means for determining the voltage-balancing requests 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.

[064] 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 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.

[065] 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.

[066] 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.

[067] In the module Mi_1, a plurality of contactors are 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.

[068] 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.

[069] With reference to figure 6, the system 1 advantageously 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 two drive assemblies (for example Ei_1, Ei_2) of the transport system. The central unit UC takes the form, for example, of a microcontroller including a plurality of inputs and a plurality of outputs.

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

- 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 (Vref_Ei_1, Vref_Ei_2) to each control unit for controlling the converter and hence the electric motor of the drive assembly;

- 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 receive, from the electrical energy management unit, in particular the state of the cells of the electrical energy storage module of the drive assembly. The processing of such a balancing request by the central unit will be explained below.

[071] 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 power 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.

[072] It is essential for a transport system such as described above to have maximum availability. It is therefore vital to optimize the management and the charging of the various electrical energy storage modules Mi_X of the transport system.

[073] In this context, it is possible to determine a target state of charge SOCcible_T to be reached when charging the electrical energy storage modules Mi_X of such a transport system by taking a plurality of factors into account. These various factors are the following:

- the siting of the charging point with respect to the journey to be made;
- the characteristics of the transport system and of its load (the overall weight and the efficiency of the system);
- the map of the journey to be made in terms of electrical autonomy, including distance and positive and negative slopes, the distance possibly varying when the transport system is used for the construction of infrastructure such as a tunnel;
- the setpoint speed of the transport system.

[074] These various parameters make it possible, specifically, to estimate, quite accurately, the electrical energy needed for the operation of the system over the journey and hence the target state of charge SOCcible_T to be reached to make it possible:

- to make the journey completely autonomously;
- to minimize electrical energy consumption when charging the storage modules;
- to increase the time for which the transport system is available, this skipping only the time just needed for charging.

[075] This technical solution accounts for the fact that each electrical energy storage module Mi_X is able to recover electrical energy when the transport system is braked. Specifically, when the system is braked, each reversible converter of the $2n$ drive assemblies makes it possible to control a transfer of the current generated in braking to the electrical energy storage module with which it is associated.

[076] To determine a target state of charge SOC_{cible_T} , it is therefore a matter of:

- dividing the journey to be made electrically autonomously into a plurality of portions, each portion having either a positive slope (uphill), a negative slope (downhill) or a zero slope;
- determining the gain or loss of electrical energy generated for each portion of the journey.

[077] The state of charge SOC_{cible_T} will be chosen within a range of values between a determined minimum value (SOC_{min}) and a determined maximum value (SOC_{max}) allowing the various constraints set above to be met. This minimum value SOC_{min} and this maximum value SOC_{max} will advantageously be below 100%.

[078] More specifically, an algorithm for determining the target state of charge SOC_{cible_T} is run for all of the available electrical energy storage modules Mi_X . This algorithm will be stored in first processing means UC1 and run by these first processing means UC1. These first processing means will for example be comprised in the central unit UC mentioned above.

[079] These first processing means UC1 thus receive, as input, and store, the following various parameters:

- the journey to be made and the number of portions P_j forming the journey, each journey portion P_j having a distance and a (positive, negative or zero) slope;
- the characteristics of the transport system.

[080] On the basis of their algorithm, the first processing means UC1 determine:

- the minimum state of charge SOC_{min} to which the set of electrical energy storage modules Mi_X must be charged in order to make said journey completely autonomously; a margin may be added in order to account for operating conditions;
- the maximum state of charge SOC_{max} to which the storage modules Mi_X must be charged in order to make the best use of regenerative braking over the journey. This maximum state of charge SOC_{max} is therefore calculated according to a state of charge of 100% reached over the journey;

- the target state of charge SOC_{cible_T} to which the set of electrical energy storage modules of the system must be charged, taking SOC_{max} and SOC_{min} into account.

[081] Of course, it may be noted that the journey may vary with time (for example when constructing infrastructure such as a tunnel). In this case, the journey may be corrected manually or automatically by accounting for the distance traveled in the last journey and the rate of progress of the work (for example speed at which the tunnel is dug).

[082] Figure 7 illustrates the operating principle of this algorithm. In this figure 7, it may be seen that the transport system 1 has to make a journey that includes, from its charging point (P0): a first portion P1 with a negative slope and a second portion P2 with a positive slope. The journey is for example a return journey. Of course, the target state of charge SOC_{cible_T} could be calculated while taking into account the fact that the transport system has to make the same journey several times (i.e. several returns) without being recharged.

[083] By way of illustration, the electrical energy storage modules of the system are charged at its charging point to a target state of charge SOC_{cible_T} of 96%. Since the first portion of the journey has a distance $D1$ and a negative slope $X1$ of 1%, the determined gain in terms of state of charge will for example be 4% over this first portion P1 of the journey. At the end of this first portion P1, the electrical energy storage modules Mi_X of the system will therefore be charged to a state of charge of 100% (96%+4%). Since the second portion P2 has a distance $D2$ and a positive slope $X2$ of 2%, the determined loss in terms of state of charge for this second portion P2 of the journey will be 9%. At the end of this second portion, the overall state of charge of the electrical energy storage modules will therefore be 91% (100%-9%).

[084] For each portion of the journey to be made, the gain or loss in terms of state of charge will be determined from the expressions below.

[085] The state of charge of the set of modules is expressed by the following relationship:

[086] $SOC = Ah / Ah_{max}$

in which:

- SOC defines the state of charge of the set of electrical energy storage modules;
- Ah corresponds to the number of available ampere hours in the set of modules;
- Ah_{max} corresponds to the maximum number of ampere hours that the set of modules is able to receive, this value being known.

[087] There is also the following expression:

$$Ah = I_{mod} * t$$

where:

- I_{mod} corresponds to the current delivered by the set of modules over time t ;
- 5 - t corresponds to the travel time of the system, this time being known from the average speed and the distance of the portion of the journey to be made;

$$I_{mod} = P / U_{mod}$$

where

- 10 - U_{mod} corresponds to the voltage delivered by the module, this voltage being known and corresponding to the average voltage delivered by the module;
- P corresponds to the power to be delivered to reach a defined speed v , according to the expression:

$$15 \quad P = F * v$$

where

- v is the speed of the transport system, which is known over the portion of the journey;
- F is the force, which depends on mass, gravity, the angle of the slope of the portion of the journey, the various frictions and various efficiencies, whether the slope is positive or negative, etc.

25 [088] From these expressions, it is understood that it is straightforward to determine the level of charge required to travel each portion of the journey as long as the characteristics of the transport system and the topology of the journey to be made are known.

[089] In the example of figure 7, the electrical energy storage modules Mi_X of the system have been charged to an overall target state of charge SOC_{cible_T} equal to SOC_{max} (i.e. 96%), allowing them to reach a state of charge equal to 100% over the journey (at the end of the first portion).

30 [090] Once the overall target state of charge SOC_{cible_T} has been determined for making the journey, the first processing means are used to determine the state of charge, denoted by SOC_Mi_X , to which each module Mi_X of the transport system must be charged.

35 [091] The first processing means UC1 are capable of determining this state of charge SOC_Mi_X by taking various constraints into account:

- the determined target state of charge SOC_{cible_T} ;

- the need to perform various management functions on each electrical energy storage module, the implementation of such a function potentially requiring a particular state of charge;
- optionally and advantageously, the state of availability of each storage module over the journey to be made.

[092] The various management functions will for example be a sequence of voltage-balancing the cells of an electrical energy storage module, then requiring charging up to a state of charge of 100%. Another management function will for example be the implementation of a complete discharge/charge cycle of a module in order to optimize its performance. In this situation, the storage module will for example not have to be charged at all so that it will be able to be completely discharged over the journey or be charged to 100% if it is halfway through its cycle.

[093] The state of availability of each module makes it possible to determine whether the module is intended to participate or otherwise in driving the transport system over each portion of the journey to be made. For various reasons, a module might in fact not participate in driving the transport system over all or some of the journey.

[094] The first processing means UC1 are therefore arranged to plan the use of the modules over time and to determine this state of charge SOC_Mi_X to which each module must be charged in order to take the various constraints defined above into account. The first processing means include for example means for reading a table listing the various states of each module in order to gather the data related to each module and to implement the corresponding operations, in particular that of determining the state of charge to be reached when recharging the module.

[095] Furthermore, according to another aspect of the invention, one or more electrical energy storage modules of the transport system 1 could be isolated from the rest of the modules. These isolated modules will not be charged and will not participate in driving the transport system 1. These might be for example modules suffering a fault or liable to suffer a fault.

[096] According to another aspect of the invention, certain modules could always be charged to one and the same state of charge, for example to 100%, while the target state of charge SOCcible_T will have to be obtained by means of the other modules.

[097] Throughout the rest of the description, a plurality of distinct states of charge, to which the various modules could be charged according to the conditions, will thus be defined:

- SOC=100%, in particular when the cells of the module must be voltage balanced, this state of charge participating in the overall target state of

charge SOCcible_T if the module is available over at least part of the journey;

- SOC=SOCcible_Mi_X corresponding to an optimal state of charge to which the module must be charged in order to take the overall state of charge SOCcible_T into account, this state of charge preferably being below 100%; it could differ from one module to the next;
- SOC=SOC_ini corresponding to holding at its initial state of charge when connecting it to the charging point. This will be the case in particular when the module will have to be fully discharged.

[098] The optimal state of charge SOCcible_Mi_X assigned to each module could be identical for all of the modules to be charged to this state of charge. It is for example calculated by a software module of the first processing means UC1 from:

- the determined overall target state of charge SOCcible_T;
- the number of modules to be charged to a state of charge of 100% and the state of charge equal to 100% of these modules;
- the number of modules to be charged to the state of charge SOC_ini and the state of charge equal to SOC_ini of these modules;
- optionally, the number of isolated modules if this is the case for certain modules of the system;
- the total number of modules of the system.

[099] Figure 8 illustrates the principle for managing the charging of the electrical energy storage modules of a transport system 1.

[100] In this figure 8, the first processing means UC1 determine the state of charge to be reached for each electrical energy storage module Mi_X of the transport system.

25 The first processing means UC1 receive, as input:

- the determined overall target state of charge SOCcible_T for making the journey, as defined above;
- the operating state of the management functions for each electrical energy storage module;
- optionally, the state of availability of each electrical energy storage module of the transport system, this potentially being particularly advantageous;
- optionally, the isolated or unisolated state of each module.

[101] Figure 8 shows, for each module Mi_X, a table giving:

- the state of availability of the module over the portion P1 of the journey and over the portion P2 of the journey;
- the operating state of a management function for voltage-balancing the module (column Eq);
- 5 - the operating state of a management function for a complete discharge/charge cycle (column Cy);
- the isolated or unisolated state (column Is) of the module.

[101] In this figure 8, it is thus noted that the module M1_1 requires its cells to be voltage-balanced. It will therefore be charged to 100% in order to carry out this
 10 balancing sequence (Eq) subsequently. The modules M1_2, M2_1 and Mn_1 will be charged to SOCcible_Mi_X determined for each one thereof (which may be identical for each one thereof). The module M2_2 will be kept at its initial state of charge, so as to be able to discharge it fully on the next journey. The module Mn_2 is isolated; it will not be charged and will not participate in driving the system.

15 [102] More specifically, it is known that each electrical energy storage module Mi_X must have its cells voltage-balanced every now and then in order to retain all of its capabilities.

[103] However, the charging of a module to a state of charge allowing the target state of charge SOCcible_T described above to be obtained does not take the
 20 voltage-balancing of its cells into account. A sequence of voltage-balancing the cells of the module must be carried out on a module charged to a state of charge SOC_Mi_X of 100%. However, if the module remains charged to 100%, it cannot benefit from the algorithm described above allowing it to be charged to the target state of charge SOCcible_Mi_X and benefit from regenerative braking opportunities
 25 on the journey.

[104] Thus, the voltage-balancing sequence is carried out only on those electrical energy storage modules which need it. Those which have to make use of voltage balancing will have to be charged to a state of charge SOC of 100% while the others could be charged to a lower state of charge, in particular to the target state of charge
 30 SOCcible_Mi_X, in order to be able to benefit from regenerative braking.

[105] By virtue of an algorithm, it is therefore a matter of determining, for each module, whether voltage balancing is required. This algorithm is stored in second processing means and run by these second processing means. Advantageously, for each module, these second processing means are at least partly formed by the
 35 electrical energy management unit associated with the electrical energy storage module. Figure 9 illustrates the algorithm implemented for each electrical energy storage module.

[106] With reference to figure 9, for a module Mi_X, the algorithm run includes the following steps:

5 [107] Step 1 – E10: this involves running a determination or test software block run by the second processing means in order to determine whether voltage balancing is required. For this, a stored decision criterion is advantageously used. This decision criterion will in particular be based on measurements of the voltage across the terminals of the cells of the electrical energy storage module. This measurement step will be carried out using voltage sensors housed in the electrical energy storage module.

10 [108] Step 2 – E20: if balancing is required, a control software block is run by the second processing means in order to notify the first processing means UC1 that voltage-balancing of the cells of the module is recommended.

[109] Step 3 – E30: this involves a test block for determining whether the balancing request has been accepted.

15 [110] Step 4 – E40: if the balancing request is validated by the first processing means UC1, the second processing means run a software block for controlling the charging to a state of charge of 100% and the implementation of a sequence of voltage-balancing the cells.

20 [111] Step 5 – E50: a test software block is run by the second processing means in order to determine whether the sequence of voltage-balancing the cells of the module has ended. This test is required to check that the balancing sequence has indeed run to completion. It may have been interrupted if the transport system 1 was used before charging had finished.

25 [112] Step 6 – E60: if the balancing sequence has ended, a software block modifies the decision criterion, for example by resetting said criterion.

[113] Step 7 – E70: if the balancing sequence has not ended, the decision criterion is kept until the balancing sequence has run to completion. Step 1 described above will then be implemented anew for the module by the second processing means.

30 [114] Step 2' – E20': if voltage balancing is not required, charging could be carried out until reaching a state of charge of less than 100%, for example equal to the target state of charge SOCcible_Mi_X set for the module. A software block is then run to control the charging of the module to this state of charge.

[115] Step 3' – E30': if the balancing request is not accepted by the first processing means, charging will advantageously be carried out to SOCcible_Mi_X.

[116] Each module will be charged by charging means, for example a charging point B (for example located at point P0 in figure 7) until reaching the state of charge determined for the module. Any known charging solution could be envisaged.

5 [117] A charge management system according to the invention advantageously includes the first processing means and the second processing means described above. Such a system will include one or more microprocessors associated with storage means. The management system will advantageously include said charging means controlled by the first processing means and the second processing means in order to charge the modules of the system to the state of charge determined for each
10 one thereof. Similarly, the method for managing the charging of the modules described above will then include a step of controlling charging to the state of charge determined for each module.

[118] The decision criterion for the requirement to voltage-balance the cells of an
15 electrical energy storage module could be of various types. Nonlimitingly, this decision criterion could take at least one alphanumeric value taking the various parameters below, whether individually or in combination, into account:

- the number of ampere hours charged to the module;
 - a list including timestamp data indicating the dates of the voltage-balancing operations performed on each module;
 - the state of health (SOH) of each module.
- 20

[119] Some of these data will be made available by the electrical management unit of each module and based on measurements of the voltage across the terminals of the cells of the module.

25 [120] From the above description, it is understood that it is advantageous to provide a solution for managing the charging of a transport system allowing both the state of charge of each electrical energy storage module of the system to be optimized and management functions to be performed regularly on the modules of the transport system. It will thus be possible to keep the system functioning optimally while
30 benefiting from the opportunities provided by current regeneration when braking.

CLAIMS

1. A method for managing the electrical charging of a plurality of electrical energy storage modules (Mi_X) that are used in an electrically powered transport system (1) that is intended to make a journey, said transport system including:

- 5 - at least two rolling assemblies (Ri_X);
- at least two electric drive assemblies (Ei_X), referred to as the first electric drive assembly and the second electric drive assembly, each of which is associated with a distinct bearing assembly, each electric drive assembly comprising:
 - 10 o at least one electric motor (MOTi_Y) for driving said rolling assembly over the ground;
 - o at least one electrical energy storage module (Mi_X) that is intended to supply said electric motor with electrical power and that includes a plurality of electrical energy storage cells;
 - 15 o at least one bidirectional voltage converter (CONVi_Y) that is arranged to control the transfer of electrical energy between said electrical energy storage module and said electric motor;
 - the electrical energy storage module of the first electric drive assembly having no electrical power connection with the electrical energy storage module of the second electric drive assembly;
 - 20 said method being characterized in that it comprises:
 - a step of determining a target state of charge (SOCcible_T) to be reached so as to be able to make said journey completely electrically autonomously and accounting for an electrical demand for charging and discharging the electrical energy storage modules resulting from the operation of the transport system over said journey;
 - 25 - a step of determining, for each storage module of the transport system, a state of charge (SOC_Mi_X) to be reached, this state of charge being determined for each module according to:
 - 30 o the determined target state of charge (SOCcible_T);
 - o the implementation of one or more management functions on the electrical energy storage module of the system.

35 2. The method as claimed in claim 1, characterized in that the state of charge (SOC_Mi_X) is also determined by accounting for a state of availability that is assigned to the electrical energy storage module over the journey.

3. The method as claimed in claim 1 or 2, characterized in that the state of charge to be reached for at least one storage module corresponds to an optimal state of charge (SOCcible_Mi_X) which is calculated from:
- the determined overall target state of charge (SOCcible_T);
 - 5 - a number of modules to be charged to a particular state of charge according to said implemented management function and the state of charge that is assigned to these modules;
 - the total number of modules of the system.
- 10 4. The method as claimed in claim 3, characterized in that said optimal state of charge is also determined by accounting for a number of modules that are isolated, i.e. that do not participate in charging or in driving said transport system (1).
- 15 5. The method as claimed in claim 3 or 4, characterized in that one management function consists of a sequence of voltage-balancing the cells of an electrical energy storage module.
- 20 6. The method as claimed in claim 5, characterized in that it includes:
- a test step (E10) for determining whether a sequence of voltage-balancing the cells of said electrical module is required;
 - a step (E20') of controlling an operation of charging the electrical energy storage module to said determined optimal state of charge, if said voltage-balancing sequence does not have to be implemented;
 - 25 - a step (E40) of controlling an operation of charging the electrical energy storage module until a second state of charge that is equal to 100% is reached and a sequence of voltage-balancing the cells once this second state of charge has been reached if said balancing sequence is required and accepted.
- 30 7. The method as claimed in claim 6, characterized in that the test step (E10) is implemented on the basis of at least one stored decision criterion having a determined value.
- 35 8. The method as claimed in claim 7, characterized in that the test step (E10) includes a step of measuring the voltage across the terminals of the electrical energy storage cells of the electrical energy storage module.
- 40 9. The method as claimed in one of claims 6 to 8, characterized in that it includes a step (E50) of checking a state of progress of the sequence of voltage-balancing the cells of the electrical energy storage module.

10. The method as claimed in claim 9, characterized in that it includes a step (E70) of holding the decision criterion at its determined value for as long as the balancing sequence is yet to be completed.

5

11. The method as claimed in claim 9 or 10, characterized in that it includes a step (E60) of modifying said value of the decision criterion, implemented after the end of the sequence of voltage-balancing the cells of the electrical energy storage module.

10 12. A system for managing the electrical charging of a plurality of electrical energy storage modules that are used in an electrically powered transport system (1) that is intended to make a journey, said transport system including:

- at least two rolling assemblies (Ri_X);
- at least two electric drive assemblies (Ei_X), referred to as the first electric drive assembly and the second electric drive assembly, each of which is associated with a distinct rolling assembly, each electric drive assembly comprising:

15

- o at least one electric motor ($MOTi_Y$) for driving said rolling assembly over the ground;

20

- o at least one electrical energy storage module (Mi_X) that is intended to supply said electric motor with electrical power and that includes a plurality of electrical energy storage cells;

- o at least one bidirectional voltage converter ($CONVi_Y$) that is arranged to control the transfer of electrical energy between said electrical energy storage module and said electric motor;

25

- the electrical energy storage module of the first electric drive assembly having no electrical power connection with the electrical energy storage module of the second electric drive assembly;

said management system comprising processing means that are arranged so as to determine an electrical state of charge to be applied to each electrical energy storage module, characterized in that said processing means comprise:

30

- a block for determining a target state of charge ($SOCcible_T$) to be reached so as to be able to make said journey completely electrically autonomously and accounting for an electrical demand for charging and discharging the modules resulting from the operation of the transport system over said journey;

35

- a block for determining, for each storage module of the transport system, a state of charge (SOC_Mi_X) to be reached, this state of charge being determined for each module according to:

40

- o the determined target state of charge (SOCcible_T);
- o the implementation of one or more management functions on the electrical energy storage module of the system.

5 13. The system as claimed in claim 12, characterized in that the state of charge (SOC_Mi_X) to be reached for each module is determined by accounting for a state of availability that is assigned to the electrical energy storage module over the journey.

10 14. The system as claimed in claim 12 or 13, characterized in that the state of charge to be reached for at least one storage module corresponds to an optimal state of charge (SOCcible_Mi_X) which is calculated from:

- the determined overall target state of charge (SOCcible_T);
- a number of modules to be charged to a particular state of charge
- 15 according to said implemented management function and the state of charge that is assigned to these modules;
- the total number of modules of the system.

20 15. The system as claimed in claim 14, characterized in that said optimal state of charge (SOCcible_Mi_X) is also determined by accounting for a number of modules that are isolated, i.e. that do not participate in charging or in driving said transport system (1).

25 16. The system as claimed in claim 14 or 15, characterized in that one management function consists of a sequence of voltage-balancing the cells of an electrical energy storage module.

30 17. The system as claimed in claim 16, characterized in that it includes:

- a test block that is arranged so as to determine whether an operation of implementing a sequence of voltage-balancing the cells of said electrical module is required;
- a block for controlling a charging operation until said determined optimal state of charge is reached, if said voltage-balancing sequence does not have to be implemented;
- 35 - a block for controlling a charging operation until a second state of charge that is equal to 100% is reached and a sequence of voltage-balancing the cells once this second state of charge has been reached if the balancing sequence is required and accepted.

18. The system as claimed in claim 17, characterized in that the test block is run on the basis of at least one stored decision criterion having a determined value.

5 19. The system as claimed in claim 18, characterized in that it includes means for measuring the voltage across the terminals of the electrical energy storage cells of the electrical energy storage module and in that said decision criterion is based on voltage measurements made by said measurement means.

10 20. The system as claimed in one of claims 17 to 19, characterized in that it includes a test block that is arranged so as to determine the state of progress of the sequence of voltage-balancing the cells of the electrical energy storage module.

15 **21.** The system as claimed in claim 17, characterized in that it includes a block for modifying said value of the decision criterion, run after the end of the sequence of voltage-balancing the cells of the electrical energy storage module.