

DESCRIPTION

POWER STORAGE UNIT OF DC ELECTRIC RAILWAY

5 **Technical Field:**

[0001] The present invention relates to power storage units of DC electric railway system that supply an electric vehicle with electric power and absorb regenerated electric power, and more particularly to the power storage units of a type that prevents
10 invalidated regeneration of the electric vehicle when an electric power storage medium is charged up to a level exceeding an arbitrary voltage.

Background Art:

[0002] In general, all of regenerated electric power produced
15 by an electric vehicle under regenerative braking is not always used for starting and/or accelerating the vehicle, and thus, the regenerated electric power that is not used becomes a surplus electric power. For achieving effective use of the surplus regenerated electric power, there has been proposed a system in
20 which in parallel with a feeder cable there is arranged an electric power storage unit that comprises an electric power storage medium and a DC/DC converter, so that the surplus regenerated electric power is absorbed by the electric power storage medium.

[0003] One drawback of the above-mentioned electric power
25 storage unit is that upon full charging of the electric power storage medium, it becomes impossible to absorb the regenerated electric power any further. When, under the fully charged condition, the electric vehicle is subjected to a regenerative braking, invalidated regeneration of the electric
30 vehicle (invalidated electric braking) occurs and thus upon this condition the regenerative operation is stopped and switching of the braking system is carried out from electric braking to mechanical braking. However, due to the switching operation, a

braking lag takes place. Due to this braking lag, a rapid braking by the mechanical brake tends to induce problems such as a failure in stopping the electric vehicle at a desired stop position, a shortening of life due to increased frictional wear of brake shoes against the wheels, etc.,.

[0004] In order to eliminate such problems, there has been proposed a system in which a load resistor is arranged through a switch in parallel with an electric double-layer capacitor and an over voltage detector is arranged to detect a fully charged condition of the capacitor. That is, upon detecting the fully charged condition, the switch is closed to apply the regenerative current to the load resistor bypassing the capacitor thereby to cause the load resistor to consume the regenerated electric power as a heat. With this, the electric double-layer capacitor is protected from over voltage. The above-mentioned system is disclosed in for example Patent Reference 1 listed hereinafter.

[0005] In addition to the above-mentioned system, another system has been proposed. In the system, when it is detected that the voltage of the capacitor is equal to or higher than a predetermined level, a control command is applied to a control unit of major elements of a feeder substation (viz., semi-conductor power converter, tapped transformer, etc.,) to reduce the output voltage of the substation thereby to prevent over voltage of the feeder cable and protect the electric double-layer capacitor from over voltage. This system is disclosed in for example Patent Reference 2 listed below.

Patent Reference 1: Japanese Laid-open Patent Application (Tokkai) 2001-206110.

Patent Reference 2: Japanese Laid-open Patent Application (Tokkai) 2003-237431.

Disclosure of the Invention

[0006] In the system disclosed by Patent Reference 1, upon fully charged condition of the electric double-layer capacitor, the

regenerative current from the electric vehicle is applied to the load resistor thereby to carry out absorption of the regenerated electric power. Although, in this system, prevention of invalidated regeneration of the electric vehicle and protection of the electric double-layer capacitor from over voltage are achieved, it is necessary to provide not only a load resistor facility but also a ventilation facility and a heat radiation facility for diffusing and treating a certain quantity of heat generated by the load resistor facility, which inevitably needs a space for mounting thereon the facilities and expenditure for the facilities. Although it is possible to reduce a chance of effecting the electric power absorption by the load resistor by increasing a capacity of the electric double-layer capacitor, this measure would cause increase in size of the electric double-layer capacitor and increase in cost of the capacitor.

[0007] In the system disclosed by Patent Reference 2, upon the capacitor voltage exceeding a predetermined level, a control is so made as to reduce the output voltage of the feeder substation. However, in this system, the voltage of feeder cable can not be lowered if another electric vehicle under power running is not present. Accordingly, in this measure, it is not always possible to assuredly protect the capacitor from over voltage induced by the regenerated electric power from the electric vehicle and the protection is affected by a running condition of another electric vehicle. Furthermore, in case where the feeder substation is of a type that has no function or facility of controlling the output voltage therefrom, such as a tapped transformer and a semi-conductor power converter, the measure is not practically used so long as a new feeder substation is not provided. Accordingly, electric facilities that can practically use the system of Patent Reference 2 are limited, and thus, if the electric facilities are of a type that can not practically use the

system, it becomes necessary to replace the electric facilities, which induces a huge cost for the facilities.

[0008] An object of the present invention is thus to provide, in a field of power storage units wherein electric power supply to an electric vehicle and absorption of regenerated electric power are performed by charging/discharging a power storage medium by DC/DC converter, a power storage unit of DC electric railway system that prevents invalidated regeneration of the electric vehicle, assuredly protects the power storage medium from over voltage, needs no load resistor facility, no ventilation facility and no heat radiation facility, needs no enlargement of the power storage medium and is practically usable in the facility of an existing feeder substation.

[0009] In order to solve the above-mentioned drawbacks, the present invention provides the following measures.

[0010] (1) In a power storage unit of DC electric railway system wherein electric power supply to an electric vehicle and absorption of regenerated electric power by the electric vehicle that has a function to reduce regenerative current are performed by charging/discharging a power storage medium by DC/DC converter, a characteristic is that the DC/DC converter is provided with an invalidated regeneration prevention control means that increases the voltage of a feeder cable up to such a level as to actuate the regenerative current reducing control function of the electric vehicle when the electric power storage medium is charged up to an arbitrary voltage.

[0011] (2) In a power storage unit of DC electric railway system wherein electric power supply to an electric vehicle and absorption of regenerated electric power by the electric vehicle that has a function to reduce regenerative current are performed by charging/discharging a power storage medium by DC/DC converter, a characteristic is that the DC/DC converter is provided with an invalidated regeneration prevention control

means that increases the voltage of a feeder cable up to such a level as to make the regenerative current of the electric vehicle zero when the electric power storage is charged up to a full level voltage.

5 [0012] (3) In a power storage unit of DC electric railway system wherein electric power supply to an electric vehicle and absorption of regenerated electric power by the electric vehicle that has a function to reduce regenerative current are performed by charging/discharging a power storage medium by DC/DC
10 converter, a characteristic is that the DC/DC converter is provided with an invalidated regeneration prevention control means that, when the electric power storage medium is charged up to an arbitrary voltage, increases the voltage of a feeder cable up to such a level as to actuate the regenerative current reducing
15 control function of the electric vehicle and increases the voltage of the feeder cable in accordance with increase of the voltage of the electric power storage medium thereby to increase a degree of reducing the regenerative current, and when the electric power storage medium is charged up to a full level voltage, increases
20 the voltage of the feeder cable up to such a level as to make the regenerative current zero due to the regenerative current reducing control function of the electric vehicle.

[0013] (4) A characteristic is that the DC/DC converter is a step up/down chopper.

25 [0014] (5) A characteristic is that the electric power storage medium is an electric double-layer capacitor.

Best Mode(s) for carrying out the Invention

[0015] Fig. 1 is a drawing showing an essential part of a feeder system for a DC electric railway, which is an embodiment
30 of the present invention. That is, in the embodiment, there is provided an invalidated regeneration prevention control means for a DC/DC converter, which, by using a regenerative current reducing control function possessed by an electric vehicle (viz., a

function to reduce a regenerative current from 100% to 0% in accordance with a pantograph point voltage that is above a specified level), increases the voltage of a feeder cable in accordance with increase of the voltage of the electric power storage medium.

[0016] The power storage unit to which the embodiment of the invention is applied is of a type wherein an electric vehicle has a regenerative current reducing control function. This control function is provided by existing electric vehicles and monitors a pantograph point voltage of the electric vehicle, so that when the voltage exceeds a specified level, the regenerative current is reduced from 100% to 0% in accordance with the voltage thereby to prevent the pantograph point voltage from increasing to an excessively high level. In general, in an electric vehicle of DC 1500V type, as is seen from Fig. 2, the control of the regenerative current is so made that when the pantograph point voltage is equal to or lower than DC 1600V, a reducing rate is controlled to 1.0 (reducing quantity 0%), when the pantograph point voltage is equal to or higher than DV 1800V, the reducing rate is controlled to 0 (zero) (reducing quantity 100%), and when the pantograph point voltage is in a range from 1600V to 1800V, the reducing rate is linearly reduced toward 0 (zero) in proportion to the voltage. A surplus amount of regenerated electric power produced due to the reduction of regenerative current is absorbed by mechanical braking. In the embodiment, an electric double-layer capacitor 4A is used as the electric power storage medium and a step up/down chopper 4B is used as the DC/DC converter. However, usage of such electric power storage medium 4A and DC/DC converter 4B is not limited to the invention.

[0017] In a DC electric railway system that practically uses an electric vehicle having the above-mentioned regenerative current reducing control function, a power storage unit 4 of the system comprises a main circuit that includes the electric double-

layer capacitor 4A and the step up/down chopper 4B, and a chopper control section 4C as a control unit.

[0018] The chopper control section 4C has a charging/discharging control function that is equal to that possessed by a conventional power storage unit, and for performing electric power supply to an electric vehicle as well as absorption of regenerated electric power, switching of up/down operation of the step up/down chopper 4B and control of a conducting rate of the chopper are carried out with reference to a comparison between a detected signal V_t of a feeder cable voltage and a charging/discharging control voltage.

[0019] For example, when, due to power running of an electric vehicle, the feeder cable voltage V_t is lowered to a value lower than a specified value, the chopper control section 4C causes the chopper 4B to take a step up operation, so that a part or all of electric power needed for running the electric vehicle is fed from the capacitor 4A as a discharge power. While, when, due to regenerative braking of the electric vehicle, the feeder cable voltage V_t is increased to a value higher than the specified value, the chopper control section 4C causes the chopper 4B to take a step down operation, so that a part or all of the regenerated power is absorbed by the capacitor 4A as a charge power. For carrying out the charging/discharging operation, a needed amount of charge/discharge power is adjusted by a conducting rate control of the step up/down chopper 4B.

[0020] In addition to the charging/discharging control function as described hereinabove, the chopper control section 4C of the embodiment is provided with an invalidated regeneration prevention control means that, when the electric double-layer capacitor 4A is charged up to an arbitrary voltage, increases the voltage of the feeder cable up to such a level as to actuate the regenerative current reducing control function possessed by the electric vehicle. Furthermore, as is seen from Fig. 3 that shows

an exemplification, the control is so made that according to increase of the voltage of the capacitor 4A, the voltage of the feeder cable is increased for increasing the regenerative current reducing degree of the electric vehicle, and when the capacitor 4A is charged up to a full level voltage, the regenerative current becomes zero. Due to provision of such invalidated regeneration prevention control means, overcharging of the capacitor 4A, viz., charging exceeding the full-charging of the capacitor, is suppressed and thus the capacitor 4A is protected from the over voltage without requiring a load resistor facility and without increasing the capacity of the capacitor 4A. Furthermore, due to the regenerative current reducing function possessed by the electric vehicle, the invalidated regeneration of the electric vehicle is suppressed.

15 [0021] In the following, with reference to a feeder system for a DC electric railway as an example based on Fig. 3, operation of the invalidated regeneration prevention control means will be described in a case wherein the working voltage of the electric double-layer capacitor 4A ranges from DC 400V to DC 1000V (full-charged voltage).

20 [0022] When the voltage of the capacitor 4A is in a range from 400V to 800V, the chopper control section 4C carries out a charging/discharging control (normal control) of the capacitor 4A so as to cause the feeder cable to have a voltage of about 1650V, and thus roughly 100% of the regenerative current of the electric vehicle is regenerated.

25 [0023] When the voltage of the capacitor 4A is nearing 1000V (full-charged voltage) and exceeds 800V that is a specified value, the invalidated regeneration prevention control means of the chopper control section 4C functions to increase the voltage of the feeder cable, so that the regenerative current reducing control function possessed by the electric vehicle 2 starts to operate thereby reducing the regenerative current. When, in this

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case, the voltage of the capacitor 4A is within a range from 800V to 1000V (full-charged voltage), the step up/down chopper 4B operates to control or adjust the voltage of the feeder cable within a range from 1650V to 1800V by its conducting rate control thereby causing the electric vehicle 2 to reduce the regenerative current. Especially, when the capacitor 4A shows a voltage of 1000V (full-charged voltage), the voltage of the feeder cable is controlled to 1800V and thus the regenerative current of the electric vehicle 2 becomes zero.

10 [0024] Accordingly, during the control by the invalidated regeneration prevention control means, a surplus energy that is not consumed by the electric vehicle 2 inevitably remains due to increase of the voltage of the feeder cable. However, because of usage of the regenerative current reducing control function, the electric vehicle 2 is suppressed from making a regenerative braking that causes an over charge exceeding the full-charging of the capacitor 4A induced by the increase of voltage of the feeder cable and mechanical braking takes place before occurrence of invalidated regeneration, and thus, invalidated regeneration is not induced. Furthermore, since the capacitor 4A is suppressed from being overcharged, over-voltage is suppressed. Furthermore, due to absence of the invalidated regeneration, undesirable rapid braking that would be caused by switching from electric braking to mechanical braking does not occur, and thus, various problems such as a failure in stopping the electric vehicle at a desired stop position, a shortening of life due to increased frictional wear of brake shoes against the wheels, etc., are solved.

25 [0025] As is described hereinabove, in a power storage unit of the present invention, there is provided a control means that functions to increase the voltage of the feeder cable in accordance with increase of the voltage of an electric power storage medium, and thus, the following advantages are obtained.

[0026] (1) Invalidated regeneration of an electric vehicle is suppressed.

[0027] (2) An electric power storage medium is protected from over-voltage.

5 [0028] (3) Since the electric power storage medium requires only a small capacity, compact and low cost construction of the power storage medium is achieved.

[0029] (4) Since a load resistor facility, a ventilation facility and a heat radiation facility are not required, a space for
10 mounting thereon these facilities is not needed and saving of expenditure for facilities is achieved.

[0030] (5) Since, due to practical usage of an existing feeder substation, replacement and modification of facilities are not needed, the present invention is widely applicable to various
15 electrical railway systems and replacement of facilities and expenditure for modification are not needed.

Brief Description of the Drawings

[0031] Fig. 1 is a drawing showing an essential part of a feeder system for a DC electric railway, which is an embodiment
20 of the present invention.

[0032] Fig. 2 is a graph showing a characteristic of regenerative current reducing function possessed by an electric vehicle.

[0033] Fig. 3 is a graph depicting a current/voltage control of
25 various portions in both a normal control and an invalidated regeneration prevention control.

CLAIMS

1. In a power storage unit of a DC electric railway system wherein electric power supply to an electric vehicle and
5 absorption of regenerated electric power by the electric vehicle that has a function to reduce regenerative current are performed by charging/discharging a power storage medium by a DC/DC converter,

the power storage unit being characterized in that the
10 DC/DC converter is provided with an invalidated regeneration prevention control means that increases the voltage of a feeder cable up to such a level as to actuate the regenerative current reducing control function of the electric vehicle when the electric power storage medium is charged up to an arbitrary voltage.

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2. In a power storage unit of a DC electric railway system wherein electric power supply to an electric vehicle and absorption of regenerated electric power by the electric vehicle that has a function to reduce regenerative current are performed
20 by charging/discharging a power storage medium by DC/DC converter,

the power storage unit being characterized in that that the DC/DC converter is provided with an invalidated regeneration prevention control means that increases the voltage of a feeder
25 cable up to such a level as to make the regenerative current of the electric vehicle zero when the electric power storage is charged up to a full level voltage.

3. In a power storage unit of a DC electric railway system
30 wherein electric power supply to an electric vehicle and absorption of regenerated electric power by the electric vehicle that has a function to reduce regenerative current are performed

by charging/discharging a power storage medium by DC/DC converter,

the power storage unit being characterized in that the DC/DC converter is provided with an invalidated regeneration prevention control means that, when the electric power storage medium is charged up to an arbitrary voltage, increases the voltage of a feeder cable up to such a level as to actuate the regenerative current reducing control function of the electric vehicle and increases the voltage of the feeder cable in accordance with increase of the voltage of the electric power storage medium thereby to increase a degree of reducing the regenerative current, and when the electric power storage medium is charged up to a full level voltage, increases the voltage of the feeder cable up to such a level as to make the regenerative current zero due to the regenerative current reducing control function of the electric vehicle.

4. A power storage unit of a DC electric railway system as claimed in Claim 1, 2 or 3, which is characterized in that the DC/DC converter is a step up/down chopper.

5. A power storage unit of a DC electric railway system as claimed in Claim 1, 2, 3 or 4, which is characterized in that the electric power storage medium is an electric double-layer capacitor.