

DESCRIPTION

DC POWER STORAGE DEVICE

Technical Field

[0001] The present invention relates to apparatus or device such as direct-current power storage apparatus which is to be connected in parallel to an external line of an electric railway and which is arranged to supply electric power to an electric vehicle in power running operation and absorbing power in regenerating operation, and more specifically to charge and discharge control system and/or method to control a power storage medium for measures against a voltage drop of an external line, measures for absorption of regenerative energy of an electric vehicle, and measures for preventing regeneration failure of an electric vehicle.

Background Art

[0002] In a direct-current feeding system, traction power substations are arranged at relatively long intervals in a quite or non-busy railway line. Therefore, for an electric railway vehicle distant from a nearest substation, a pantograph point voltage may decrease below a lower limit of rated voltage due to a voltage drop of an external line at the time of large current for starting the vehicle, for example. To compensate for the voltage drop, a traction power substation (DCVR) is provided or a notch restraint control is performed in the electric vehicle.

[0003] Moreover, in a quiet or non-busy railway line, an electric vehicle in the regenerating mode has only a limited

opportunity to have regenerated energy absorbed by another vehicle as energy for power running, and hence tends to fall in regeneration failure (inability of electric braking). Even in a busy or active railway line, regeneration failure can occur in an electric vehicle in the regeneration mode when the power running operation ends in another vehicle, and the load decreases abruptly.

[0004] When the regeneration is canceled or fails, the electric vehicle stops the regenerating operation, and changes over the brake mode from electric brake to mechanical brake. This brake mode changeover operation causes a delay in braking which further causes failure in stopping the vehicle at a predetermined position, and shortened service life due to wear between a wheel and a brake shoe in hard braking of the mechanical brake. There are the following methods for absorbing regenerated electric power to prevent the regeneration failure.

[0005] (1) Regeneration method of supplying regenerative power to alternating-current power source by an inverter: As shown in FIG. 4(A), dc power regenerated by a regenerating electric vehicle 1 is converted to ac power of a controlled voltage and a controlled frequency by a combination of an inverter 2 connected with an external line as a dc supply side, and a transformer 3 for the inverter, and the ac power is supplied to the ac power source side.

[0006] This method requires the ac load to absorb the regenerated power, and further requires the transformer for the inverter, an ac breaker, the inverter and a dc breaker, so that the system is costly as a whole.

[0007] (2) Regeneration method of supplying regenerative power to a regenerative resistance device by a chopper: As shown in FIG. 4(B), a chopper 4 transforms dc power regenerated by a regenerating electric vehicle 1, to dc power of controlled voltage, and a regenerative resistance device 5 absorbs this dc power as heat.

[0008] This method is unable to make effective use of the regenerative power since all the regenerative power is absorbed thermally by the resistance device, and this method requires the large-sized resistance device.

Moreover, this method further requires ventilating equipment and heat releasing equipment for dissipating heat generated by the resistance device, and the equipment is relatively costly, inclusive of the chopper.

[0009] (3) Regeneration method utilizing dc power storage apparatus: As shown in FIG. 4(C), on a direct-current side of a rectifier 6, there is provided a direct-current power storage apparatus composed of a step-up and step-down chopper 7 and a direct-current power storage unit 8. When the external line voltage exceeds the upper limit of its rated voltage range because of the regenerating operation of an electric vehicle, then the external line voltage is controlled to a lower voltage level by a voltage decrease control of chopper 7, and regenerated power is absorbed as a charging current to the direct-current power storage unit 8 through the chopper 7 from the external line (cf. patent document 1, and patent document 2).

[0010] When the external line voltage becomes lower than the lower limit of the rated voltage range because of

the power running operation of an electric vehicle, then the external line voltage is controlled to a higher voltage level by a voltage increase control of the chopper 7, and power is supplied from the direct-current power storage unit 8 through the chopper 7 to the external line. Thus, this system can be used as measures against the voltage drop, and used for leveling the load as viewed from the alternating-current source side.

[0011] FIG. 5 shows a main circuit configuration of the direct-current power storage apparatus. The step-up and step-down chopper 7 includes a high voltage side arm; a low voltage side arm; and a reactor L. The high voltage side arm includes a semiconductor switch SW1 which has a first end connected with the external line and a second end, and which is connected so that the semiconductor switch can control the charging current flowing from the external line; and an antiparallel diode D1 connected in antiparallel to semiconductor switch SW1. The low voltage side arm includes a semiconductor switch SW2 which has a first end connected with the second end of the semiconductor switch SW1 and a second end, and which is connected in series with the switch SW1 in the same orientation as the switch SW1 to control the current; and an antiparallel diode D2 connected in antiparallel to semiconductor switch SW2. The reactor L has a first end connected with the second end of the semiconductor switch SW1, and a second end connected with an electric double layer capacitor EDLC.

[0012] When the external line voltage becomes higher than an upper limit of a rated voltage range due to the regenerating operation of electric vehicle 1, as shown in

FIG. 6, the thus-constructed power storage system decreases the external line voltage with the control of the chopper. That is, the system controls the switch SW1 to perform switching operations so as to allow a charging current to flow from the external line through switch SW1 and reactor L, to EDLC during an on period; and to charge EDLC with a circulating flow from reactor L, through EDLC and D2 during an off period. By so doing, the system regenerates power as charging energy to EDLC.

[0013] When the external line voltage becomes lower than a lower limit of the rated voltage range due to the power running operation of electric vehicle 1, as shown in FIG. 6, the power storage system increases the external line voltage with the control of the chopper. That is, the system controls the switch SW2 in a chopping mode to accumulate electromagnetic energy in the reactor L by causing a short-circuiting current to flow from EDLC through L and SW2, to EDLC during the on period; and to restrain a voltage drop of the external line by causing a discharging current to flow from EDLC through reactor L and D1, to the external line on the off period.

[0014] The direct-current power storage apparatus may employ a battery in addition to the electric double layer capacitor. The battery is superior in energy storage for a long time and amount of storage. However, the battery is inferior in rapid charging and discharging characteristics. Therefore, the battery might cause a delay in charging of rapidly rising regenerative power or a delay in a discharging operation following an abrupt change of the load at the time of starting or acceleration of an electric

vehicle, and thereby the battery might incur abrupt change in the external line voltage or regeneration failure. On the other hand, the electric double layer capacitor is superior in rapid charging and discharging characteristics, and the electric double layer capacitor can absorb regenerative energy from an electric vehicle properly, and respond quickly to abrupt change in load.

Patent document 1: Published Japanese Patent Application JP 2000-233669 A

Patent document 2: Published Japanese Patent Application JP 2001-260718 A

Disclosure of Invention

[0015] [First Task] To restrain a voltage decrease of the external line with the dc power storage apparatus including the electric double layer capacitor and step-up and step-down chopper, in the configuration of FIG. 5, the terminal voltage (standby voltage) of the electric double layer capacitor is set at a value lower than the lower limit voltage of the rated voltage range of the external line voltage, and a discharge from the electric double layer capacitor to the external line by the route of reactor L → diode D1 is prevented. Moreover, to maximize the amount of electric power (the amount of stored power) which can be supplied from the electric double layer capacitor, the terminal voltage of the electric double layer capacitor is set to a high value near the lower limit voltage of the rated voltage range of the external line voltage.

[0016] When, in an example of a 1500V system, the external line voltage is lower than or equal to 1200V (the lower limit of the rated voltage range of the external line

voltage), and power is supplied from the electric double layer capacitor, the terminal voltage (standby voltage) of the electric double layer capacitor is set lower than or equal to 1200V, and the system is arranged to restrain a voltage drop of the external line voltage by a voltage increase control with the chopper.

[0017] In the configuration of FIG. 5, the amount of stored electric energy of the electric double layer capacitor is limited because the terminal voltage of the electric double layer capacitor is set lower than the lower limit of the rated voltage range of the external line voltage. It is possible to increase the amount of stored electric power by increasing the number of parallel units of the electric double layer capacitor and increasing the controllable current capacity of the step-up and step-down chopper. However, this measure increases the size of the dc power storage apparatus and increases the cost.

[0018] [Second Task] When the dc power storage apparatus is used to restrain the voltage drop and absorb the regenerated power, the systems of the above-mentioned patent documents are arranged to restrain the voltage drop by increasing the terminal voltage of the electric double layer capacitor with the chopper in the voltage increase (or step-up) control mode in the case of voltage decrease of the external line voltage, and to absorb the regenerated power by decreasing the external line voltage with the chopper in the voltage decrease (step-down) control mode in the case of voltage increase of the external line voltage. In this case, in order to use for both of the measures against voltage drop and the measures to

absorb regenerative power, the same voltage range of the terminal voltage (standby voltage) of the electric double layer capacitor is used for both of the discharging operation to restrain the voltage drop and the charging operation to absorb regenerative power. However, at the time of operation to restrain the voltage drop, the system can restrain the voltage drop more effectively in a fully charged state in which the electric double layer capacitor is fully charged and hence its terminal voltage is high. At the time of operation to absorb regenerated power, the system can absorb more energy in a state in which the amount of charged energy is lower in the electric double layer capacitor and hence its terminal voltage is lower. Therefore, since the amount of supplied discharge electric energy and the amount of absorbed charge energy are utilized in the same voltage range, the amount of energy to perform both the function of voltage drop restraint and the function of regenerative power absorption becomes low as compared to the amount of energy in the fully charged state and the amount of energy in the minimally charged state, so that the system is unable to perform both functions satisfactorily.

[0019] Therefore, in order to secure the amount of charge/discharge energy satisfying both functions of voltage drop restraint and regenerative power absorption, it is necessary to increase the number of parallel units of the electric double layer capacitor and increasing the controllable current capacity of the step-up and step-down chopper as in the above-mentioned first problem. As a

result, this technique increases the size of the dc power storage apparatus and increases the cost.

[0020] In order to increase the amount of charge/discharge energy, it is possible to employ a dual system including a first dc power storage unit having a lower terminal voltage (standby voltage) for the function of voltage drop restraint, and a second dc power storage unit having a higher terminal voltage for the function of regenerative power absorption. However, this dual system increases the size of the system and the cost.

[0021] [Third Task] When the power storage medium, such as the electric double layer capacitor, is in the fully charged state, the systems of the above-mentioned patent documents are unable to absorb regenerative power, and the regeneration failure occurs when an electric vehicle performs a regenerating operation. Therefore, there arises a need for providing a resistor device for absorbing regenerative power. Moreover, the power storage medium remains in the fully charged state until some vehicle starts a power running operation. Therefore, if the regenerative operation is continued, the regeneration failure occurs consecutively.

[0022] It is an object of the present invention to provide a direct-current power storage apparatus or system suitable for increasing a sum of an amount of power supply to an external line and an amount of power absorbed as compared to a conventional system, without increasing the size and cost of the direct-current power storage apparatus, and more specifically to make it possible to improve the function of the external line voltage drop restraint and

regenerative power absorption and to prevent the regeneration failure.

[0023] According to the present invention, to solve the above-mentioned problems, a direct-current power storage apparatus or system comprises a dc/dc converter, such as a step-up and step-down chopper, connected between an external line and a power storage medium such as an electric double layer capacitor. When an external line voltage becomes higher than an upper limit of a rated voltage range of the external line because of an increase of the external line voltage in a no-load state toward a no-load voltage of a rectifier which is higher than the upper limit, the apparatus makes a charging conduction path and thereby charges the power storage medium to the rectifier's no-load voltage. As the measures for regenerative power absorption, when the external line voltage (the voltage at a terminal connecting the chopper with the external line) becomes higher than the upper limit, the apparatus makes the conduction path to cause the power storage medium to absorb regenerated power of a regenerating vehicle as the charging energy. When the pantograph point voltage of the regenerating vehicle increases, the apparatus prevents the regeneration failure of the electric vehicle by utilizing the regenerative current squeezing function of the electric vehicle. As the measures against voltage drop, when the external line voltage becomes lower than a lower limit of the rated voltage range of the external line, the apparatus enables a discharge from the power storage medium to the external line with a voltage decrease control or a voltage increase control of

the terminal voltage of the power storage medium, and thereby holds the external line voltage at the lower limit. The direct-current power storage apparatus or system has the following construction.

[0024] (1) A direct-current power storage apparatus comprises a dc/dc converter to be connected between a power storage medium and an external line. The dc/dc converter comprises: a regenerative power controlling means or section to make conductive connection between the external line and the power storage medium to charge or discharge the power storage medium when an external line voltage becomes higher than an upper limit of a rated voltage range of the external line, and to break a discharging path from the power storage medium to the external line when the external line voltage becomes lower than the upper limit; and a voltage drop restraining means or section to discharge the power storage medium toward the external line while decreasing a terminal voltage of the power storage medium when the external line voltage becomes lower than a lower limit of the rated voltage range of the external line and the terminal voltage of the power storage medium is higher than the external line voltage, and to discharge the power storage medium toward the external line while increasing the terminal voltage of the power storage medium when the external line voltage becomes lower than the lower limit and the terminal voltage of the power storage medium is lower than the external line voltage.

[0025] (2) When the upper limit voltage is exceeded by absorption of regenerative power from an electric vehicle,

and the external line voltage increases by conduction between the power storage medium and the external line, the regenerative power controlling means or section restrains the terminal voltage of the power storage medium to a level lower than or equal to a maximum voltage of the terminal voltage in cooperation with a regenerative current squeezing operation of a regenerative current squeezing function of the electric vehicle.

[0026] (3) the dc/dc converter connects the external line and the power storage medium in a no-load state of the external line, and thereby charges the power storage medium until the terminal voltage of the power storage medium reaches a no load voltage of a rectifier.

[0027] (4) The dc/dc converter includes means or a device which charges the power storage medium from the external line, while decreasing the external line voltage if the terminal voltage is lower than the external line voltage, and while increasing the external line voltage if the terminal voltage is higher than the external line voltage, when the external line voltage is higher than or equal to the lower limit of the rated voltage range and the terminal voltage of the power storage medium is lower than or equal to the upper limit of the rated voltage range.

[0028] (5) The dc/dc converter includes a discharge control switch to control or cut off a discharging current from the power storage medium to the external line when the terminal voltage of the power storage medium is higher than the external line voltage.

[0029] (6) The dc/dc converter comprises a main circuit which comprises:

a step-up and step-down chopper including a high voltage side arm including a semiconductor switch SW1 which is arranged in a direction to control a charging current flowing from the external line and which includes a first end connected with the external line and a second end, and an antiparallel diode D1 connected in anti-parallel to the semiconductor switch SW1 of the high voltage side arm, a low voltage side arm including a semiconductor switch SW2 which is arranged in the direction of the semiconductor switch SW1 and which is connected in series with the second end of the semiconductor switch SW1, and an antiparallel diode D2 connected in anti-parallel to the semiconductor switch SW2, and a reactor including a first end connected with the second end of the semiconductor switch SW1 and a second end; and

a discharge control switch including a semiconductor switch SW3 connected between the second end of the reactor L and the power storage medium and arranged in a direction to control a discharging current from the power storage medium, and an antiparallel diode D3 connected in anti-parallel to the semiconductor switch SW3.

Best Mode(s) for Carrying Out the Invention

[0030] FIG. 1 shows, in a circuit diagram, a direct-current power storage apparatus or system according to one embodiment of the present invention. The main circuit section of FIG. 1 is almost the same as the circuit shown in FIG. 5. Unlike the circuit of FIG. 5, the circuit of FIG. 1 additionally includes a discharge control switch 9 connected between the second reactor end of reactor L and the before-mentioned power storage medium. The discharge

control switch 9 is composed of a semiconductor switch SW3 so oriented as to control a discharge current from the power storage medium; and an antiparallel diode D3 connected in antiparallel to the semiconductor switch SW3.

[0031] A control unit or control device 10 functions to control the step up voltage and the step down voltage of the chopper 7. Moreover, control unit 10 functions to control the switching operation and the conduction/cutoff (on/off) of the discharge control switch 9. Control unit 10 performs various control operations as mentioned below in accordance with various voltage setting conditions and voltage detection signals. Accordingly, control unit 10 is provided with the following control means.

[0032] In the specification and drawings of this application, "external line" is a generic term denoting a direct-current side of a rectifier 6 of a feeding substation, a feed line output side of a power storage apparatus, a feeding line, an overhead wire and a trolley wire.

[0033] (a) The employed double layer capacitor is a double layer capacitor having a charging voltage range whose upper limit is higher than or equal to a maximum voltage which can appear in the external line by regenerative power of an electric vehicle. In a no-load state of the external line, the double layer capacitor is charged to a rectifier's no-load voltage which is higher than the upper limit of the rated voltage range of the external line.

[0034] (b) The direct-current power storage apparatus or system implements the measures for regenerative power absorption and the measures for regeneration failure

prevention in the following manner. When the external line voltage becomes higher than the upper limit voltage of the rated voltage range, the switches SW1 and SW3 are turned on (into the conductive state) to connect the external line and the electric double layer capacitor and thereby to cause the double layer capacitor to absorb the regenerated power as the charging power. With this power absorption, the system prevents the regeneration failure of an electric vehicle due to an abrupt increase of the external line voltage, and makes effective use of regenerated power by discharging the absorbed regenerative energy from the electric double layer capacitor to a power running electric vehicle.

[0035] When the external line voltage continues to rise due to this power absorption, the system controls the terminal voltage of the double layer capacitor and the external line voltage so as to prevent an increase beyond a maximum voltage, in cooperation with a regenerative current squeezing operation by a regenerative current squeezing function of an electric vehicle. At the same time, the system prevents the regeneration from being canceled by the regenerative current squeezing control of the electric vehicle even in this state.

[0036] (c) The direct-current power storage apparatus or system implements the measures against a voltage drop in the following manner. When the external line voltage becomes lower than the lower limit voltage of the rated voltage range, the system controls the semiconductor switch SW3 of discharge control switch 9 in a switching control mode if the terminal voltage of the electric double

layer capacitor is higher than the external line voltage. By this switching control of semiconductor switch SW3, the system performs a voltage decrease control to decrease the terminal voltage of the electric double layer capacitor, and discharges the double layer capacitor toward the external line. By the discharge from the electric double layer capacitor, the system holds the external line voltage higher than or equal to the lower limit voltage of the rated voltage range of the external line voltage. Furthermore, when the terminal voltage of the electric double layer capacitor becomes lower than the external line voltage by this discharge, the system puts the semiconductor switch SW3 to an on control state (the conductive state) and controls the semiconductor switch SW2 of chopper 7 in the switching control mode. By this changeover of the control states of SW3 and SW2, the system continues the discharge from the double layer capacitor while performing a voltage increase control to increase the terminal voltage of the electric double layer capacitor, and thereby holds the external line voltage higher than or equal to the lower limit voltage of the rated voltage range of the external line.

[0037] The squeezing of the regenerative current is the function provided in existing electric vehicles. In this squeezing control, a system monitors the pantograph point voltage of an electric vehicle. When the pantograph point voltage is higher than a preset voltage, the system squeezes the regenerative current from 100% to 0% and thereby prevents an excessive increase of the pantograph point voltage. In general, in the case of electric vehicles of DC 1500 V system, as shown in FIG. 2, a squeeze rate is

equal to 1.0 (a squeeze quantity is 0%) when the pantograph point voltage is lower than or equal to DC 1600V, and the squeeze rate is equal to 0 (the squeeze quantity is 100%) when the pantograph point voltage is higher than or equal to DC 1800V. Between 1600V and 1800V, the squeeze rate is decreased to zero linearly in proportion to the voltage. The system restrains the regenerative current in this way. The mechanical brake absorbs surplus braking energy produced by this squeezing control of the regenerative current.

[0038] The following is detailed explanation on concrete examples when control operations are applied to the 1500V system for the measures for voltage drop restraint, the measures for regenerative power absorption and the measures for regeneration failure prevention.

[0039] (1) Operating conditions of feeding system: The rated voltage range of the external line is DC 1600V (upper limit) ~ 1200V (lower limit), and the no-load voltage of a rectifier 6 of a feeding substation is DC 1620V. The maximum charging voltage of the electric double layer capacitor EDLC is DC 1800V.

[0040] (2) No load operation: Control unit 10 controls the semiconductor switch SW1 of chopper 7 to the on (conductive) control state when the external line voltage is higher than or equal to 1600V. When the electric double layer capacitor EDLC is lower than 1600V, the electric double layer capacitor is charged from the rectifier 6 of the feeding substation until the charging voltage reaches the no load voltage (1620V) of the rectifier 6.

[0041] Normal load operation: When an electric vehicle is operated in the power running mode, and the external line voltage becomes lower than the rectifier no load voltage (1620V), the control unit 10 performs, in parallel to the feeding from rectifier 6, the power supply from the electric double layer capacitor by the on control of discharge control switch 9 since the external line voltage and the terminal voltage of the electric double layer capacitor are in equilibrium. However, control unit 10 turns off the discharge control switch 9 when the external line voltage becomes lower than 1600V (but higher than or equal to 1200V). Therefore, in this case, the powering energy is supplied only from the rectifier 6 within the rated voltage range of the external line.

[0042] (4) Measures for regenerative power absorption and measures for regeneration failure prevention: When, as shown in FIG. 3, the external line voltage is increased by regenerated power of an electric vehicle, and the external line voltage becomes higher than the upper limit (1600V) of the rated voltage range of the external line voltage (at a time instant t_1), the control unit 10 turns on the semiconductor switch SW1 of the step-up and step-down chopper 7 and turns on the semiconductor switch SW3. In this case, since the terminal voltage of electric double layer capacitor EDLC is also 1600V, the system causes the charging current to flow from the external line to electric double layer capacitor EDLC by the on control of semiconductor switch SW1, and thereby absorbs the regenerated power by this charging operation.

[0043] By this charging operation with the regenerated power of the electric vehicle, the terminal voltage of electric double layer capacitor EDLC increases, and the pantograph point voltage of the electric vehicle increases together. With this increase of the pantograph point voltage, the electric vehicle activates the squeezing function, and decreases the regenerative current. If the regenerative operation of the electric vehicle ends (the rise of the external line voltage ends and the external line voltage decreases toward the no load voltage (1620) of the rectifier, as shown by a curve A in FIG. 3), the terminal voltage of electric double layer capacitor EDLC decreases spontaneously by the on control of semiconductor switch SW3 because of such action as to keep voltage equilibrium between the external line voltage in this section and the external line voltages in the surrounding sections. Then, the terminal voltage of electric double layer capacitor EDLC settles down to the rectifier's no load voltage (1620V) if the no-load state remains. When the external line voltage is higher than the upper limit voltage, power is supplied from the electric double layer capacitor EDLC until the rectifier no load voltage to a powering electric vehicle if any. Below the no load voltage, power is supplied to the electric vehicle from the rectifier and the electric double layer capacitor EDLC in parallel, and the external line voltage settles down under the upper limit voltage, by the action of the powering vehicle (as shown by a curve B in FIG. 3).

[0044] When the terminal voltage of electric double layer capacitor EDLC becomes lower than the upper limit

(1600V) of the rated voltage range of the external line, the control unit 10 stops the discharging operation of electric double layer capacitor EDLC by the off control of the semiconductor switch SW3. The electric vehicle receives the power supply only from rectifier 6.

[0045] When the regenerating operation of the electric vehicle continues, and the terminal voltage of electric double layer capacitor EDLC reaches the maximum voltage (1800V)(at a time instant t_2), the regenerative current from the electric vehicle is reduced to zero by the current squeezing operation. Therefore, though the external line voltage may reach 1800V temporarily beyond the upper limit (1600V) of the rated voltage range, the system prevents further increase of the external line voltage by the reduction of the regenerative current to zero, and thereby prevents failure of the regeneration.

[0046] Therefore, in the measures for regenerative power absorption and the measures for prevention of regeneration failure, the external line voltage may increase temporarily beyond the upper limit (1600V) of the rated voltage range, but the external line voltage is decreased finally to a level lower than or equal to the rectifier no load voltage or the rated voltage's upper limit. Thus, the terminal voltage of electric double layer capacitor EDLC is controlled within the range of 1600V ~ 1800V.

[0047] (5) Measures against voltage drop: When, as shown in FIG. 3, an electric vehicle is operated in the power running mode, and the external line voltage becomes lower than the lower limit (1200V)(at an instant t_3), the control unit 10 decreases the terminal voltage of electric

double layer capacitor EDLC by switching control of the semiconductor switch SW3, starts a discharging operation from electric double layer capacitor EDLC through reactor L and diode D1, and thereby restrains a voltage drop in cooperation with power supply from rectifier 6. When the external line voltage is returned, by the operation to restrain the voltage drop, to a level higher than or equal to the lower limit (1200V)(at a time instant t_4 , as shown by a curve C in FIG. 3), the control unit 10 stops the discharge of electric double layer capacitor EDLC by turning off semiconductor switch SW3, charges the electric double layer capacitor EDLC by changing over the operation of the step-up and step-down chopper to the voltage increase control (as shown by a curve C' in FIG. 3), and stops the control at the charged state to 1600V.

[0048] When the external line voltage remains under the lower limit voltage (1200V), and the terminal voltage of electric double layer capacitor EDLC becomes lower than the external line voltage (at a time instant t_5), the control unit 10 turns the semiconductor switch SW3 to the on control state, and the semiconductor switch SW2 of the step-up and step-down chopper 7 to the switching control mode. By so doing, the control unit 10 increases the terminal voltage, continues the discharge, and thereby restrains the voltage drop of the external line voltage in cooperation with the power supply from rectifier 6. With this discharge, the terminal voltage of electric double layer capacitor EDLC decreases below the lower limit voltage (1200V). When the external line voltage is returned to a level higher than or equal to the lower limit (1200V) by this

voltage drop restraint (at a time instant t_6 , as shown by a curve D in FIG. 3), the control unit 10 charges the electric double layer capacitor EDLC by the voltage decrease control of up/down chopper 7 (as shown by a curve D' in FIG. 3), and terminates the voltage decrease control at the charged state to 1600V.

[0049] When the voltage drop of the external line continues, and the terminal voltage of electric double layer capacitor EDLC decreases to the minimum voltage (500V) by the discharge (at a time instant t_7), the control unit 10 stops the control of the step-up and step-down chopper 7. When the power running operation of the electric vehicle ends (at a time instant t_8) and the external line voltage returns to a level equal to or higher than 1200V (at a time instant t_9 , as shown by a curve E), the system charges the electric double layer capacitor EDLC (as shown by a curve E' in FIG. 3).

[0050] Thus, the terminal voltage of electric double layer capacitor EDLC is controlled in the range of 500V ~ 1600V.

[0051] That is, at the time of the measures for voltage drop restraint, this system makes it possible to charge or discharge the electric double layer capacitor EDLC in a wider voltage range (500V~1600V) as compared to a system of earlier technology, and to significantly increase the amount of power which can be supplied for the voltage drop restraint, even though the capacity of electric double layer capacitor remains unchanged from that of the system of the earlier technology, (without the need for increasing the number of parallel elements).

[0052] In the illustrated example, the dc/dc converter is composed of the step-up and step-down chopper and the discharge control switch. However, it is possible to achieve equivalent effects and operations by employing a charging and discharging circuit having a configuration different from the illustrated example, for enabling the charge and discharge between a power storage medium such as EDLC and an external line.

[0053] The system of the illustrated example is arranged to perform the charge/discharge control to control the terminal voltage of the electric double layer capacitor near the upper limit voltage of the rated voltage range of the external line in the no load state and the normal load state of the external line. However, the system may be arranged to control the terminal voltage of the electric double layer capacitor between the lower limit voltage and the upper limit voltage of the rated voltage range of the external line.

[0054] For example, the terminal voltage of the electric double layer capacitor is set at an intermediate value between the lower limit voltage and upper limit voltage. From this state, the system acts to satisfy both of the function for the measures for voltage drop restraint and the function for the measure for regenerative power absorption. Moreover, when the terminal voltage of the electric double layer capacitor becomes higher than or equal to the no-load voltage of the rectifier, the system allows the terminal voltage of the double layer capacitor to decrease spontaneously while maintaining voltage balance in the entirety of the external line even if there is no power

running vehicle. When the terminal voltage of the double layer capacitor continues to increase by the continuation of power regenerating operation in one or more vehicles, the system prevents the regeneration failure by utilizing the current squeezing control of the electric vehicle.

[0055] In the illustrated example, the power storage medium includes an electric double layer capacitor. It is possible to achieve similar effects and operations by employing, as the power storage medium, a hybrid capacitor, a large-capacity capacitor, and/or a battery. Moreover, it is optional to provide a dead band to a predetermined voltage used for controlling a semiconductor switch, to prevent chattering of the semiconductor switch.

[0056] As explained above, the system according to this invention can absorb regenerative power when the external line voltage exceeds the upper limit voltage of the rated voltage range, and restrain a voltage drop when the external line voltage decreases below the lower limit voltage of the rated voltage range.

[0057] Moreover, the power storage apparatus makes it possible to charge and discharge an electric double layer capacitor in a wider voltage range as compared to the system of the earlier technology, and to absorb regenerative power though the energy storage quantity of the double layer capacitor is equal to or greater than the quantity in the fully-charged state of the device of the earlier technology. Accordingly, the system can satisfy both the function for voltage drop restraint and the function for regenerative power absorption. When the terminal voltage of the double layer capacitor becomes

higher than or equal to the no-load voltage of the rectifier, the system causes a spontaneous decrease of the terminal voltage of the double layer capacitor with the voltage balance in the whole of the external line system even if there is no powering vehicle. Even if the terminal voltage of the double layer capacitor continues to rise by consecutive power regenerating operations, the system can prevent the failure of the regeneration by the use of the current squeezing control of an electric vehicle.

[0058] Furthermore, it is possible to significantly increase the quantity of power which can be supplied for the voltage drop restraint, without incurring an increase of the size of the system and an increase of the cost.

Brief Description of Drawings

[0059] FIG. 1 is a circuit diagram showing a direct-current power storage apparatus according to one embodiment of the present invention.

[0023] FIG. 2 is a graphic view illustrating a regenerative current squeezing characteristic of an electric vehicle which can be employed in the power storage apparatus of FIG. 1.

[0024] FIG. 3 is a view of voltage waveforms for illustrating operations of the power storage apparatus of FIG. 1 for preventing the regeneration failure and for restraining a voltage drop.

[0025] FIGS. 4 are schematic views for illustrating three different power regenerating systems of earlier technology.

[0026] FIG. 5 is a circuit diagram showing a direct-current power storage apparatus of the earlier technology.

[0027] FIG. 6 is a view of waveforms for illustrating operation of the power storage apparatus of FIG. 5.

CLAIMS

- 1 1. A direct-current power storage apparatus comprising a
2 dc/dc converter to be connected between a power storage
3 medium and an external line of a dc electric railway, and
4 which comprises,
5 a regenerative power controlling means to make
6 conductive connection between the external line and the
7 power storage medium to charge or discharge the power
8 storage medium when an external line voltage becomes
9 higher than an upper limit of a rated voltage range of the
10 external line, and to break a discharging path from the
11 power storage medium to the external line when the
12 external line voltage becomes lower than the upper limit;
13 and
14 a voltage drop restraining means to discharge the
15 power storage medium toward the external line while
16 decreasing a terminal voltage of the power storage medium
17 when the external line voltage becomes lower than a lower
18 limit of the rated voltage range of the external line and the
19 terminal voltage of the power storage medium is higher
20 than the external line voltage, and to discharge the power
21 storage medium toward the external line while increasing
22 the terminal voltage of the power storage medium when the
23 external line voltage becomes lower than the lower limit
24 and the terminal voltage of the power storage medium is
25 lower than the external line voltage.
- 1 2. The direct-current power storage apparatus as claimed
2 in Claim 1, wherein, when the upper limit is exceeded by

3 absorption of regenerative power from an electric vehicle,
4 and the external line voltage increases by conduction
5 between the power storage medium and the external line,
6 the regenerative power controlling means restrains the
7 terminal voltage of the power storage medium to a level
8 lower than or equal to a maximum voltage of the terminal
9 voltage in cooperation with a regenerative current
10 squeezing operation of a regenerative current squeezing
11 function of the electric vehicle.

1 3. The direct-current power storage apparatus as claimed
2 in Claim 1 or 2, wherein the dc/dc converter connects the
3 external line and the power storage medium in a no-load
4 state of the external line, and thereby charges the power
5 storage medium until the terminal voltage of the power
6 storage medium reaches a no load voltage of a rectifier.

1 4. The direct-current power storage apparatus as claimed
2 in Claim 1, 2 or 3, wherein the dc/dc converter includes a
3 device which charges the power storage medium from the
4 external line, while decreasing the external line voltage if
5 the terminal voltage is lower than the external line voltage,
6 and while increasing the external line voltage if the
7 terminal voltage is higher than the external line voltage,
8 when the external line voltage is higher than or equal to
9 the lower limit of the rated voltage range and the terminal
10 voltage of the power storage medium is lower than or equal
11 to the upper limit of the rated voltage range.

1 5. The direct-current power storage apparatus as claimed
2 in Claim 1, 2, 3 or 4, wherein the dc/dc converter includes
3 a discharge control switch to control or cut off a
4 discharging current from the power storage medium to the
5 external line when the terminal voltage of the power
6 storage medium is higher than the external line voltage.

1 6. The direct-current power storage apparatus as claimed
2 in Claim 1, 2, 3, 4 or 5, wherein the dc/dc converter
3 comprises a main circuit which comprises:
4 a step-up and step-down chopper including
5 a high voltage side arm including a
6 semiconductor switch SW1 which is arranged in a direction
7 to control a charging current flowing from the external line
8 and which includes a first end connected with the external
9 line and a second end, and an antiparallel diode D1
10 connected in anti-parallel to the semiconductor switch SW1,
11 a low voltage side arm including a semiconductor
12 switch SW2 which is arranged in the direction of the
13 semiconductor switch SW1 and which is connected in series
14 with the second end of the semiconductor switch SW1, and
15 an antiparallel diode D2 connected in anti-parallel to the
16 semiconductor switch SW2, and
17 a reactor including a first end connected with the
18 second end of the semiconductor switch SW1 and a second
19 end; and
20 a discharge control switch including a semiconductor
21 switch SW3 connected between the second end of the
22 reactor L and the power storage medium and arranged in a
23 direction to control a discharging current from the power

24 storage medium, and an antiparallel diode D3 connected in
25 anti-parallel to the semiconductor switch SW3.