

Description

Title of Invention: DIRECT AC POWER CONVERSION DEVICE

Technical Field

- 5 [0001] The present invention relates to a direct AC power converter, and particularly relates to a configuration having a rectifying circuit, an inverter, and a boost chopper.

Background Art

- [0002] Patent Documents 1 and 2, and Non-Patent Document 1 introduce direct AC
10 power converters. In each of these direct AC power converters, a boost chopper is used and receives an electric power from a rectifying circuit and supplies the electric power to an inverter so that pulsation of an instantaneous power is reduced.

Prior Art Documents

- 15 Patent Documents
- [0003] Patent Document 1: Japanese Patent Application Laid-Open No. 2011-193678
Patent Document 2: Japanese Patent Application Laid-Open No. 2012-135184

Non-Patent Document

- 20 [0004] Non-Patent Document 1: Ohnuma, Itoh: "Experimental Verification of Single Phase to Three Phase Converter Using an Active Buffer circuit with a Charge Circuit" , IEEJ 2010 Industry Applications Society Conference 1-124, pp. I-587-590 (2010)

Summary of Invention

- 25 Problems to be Solved by the Invention

[0005] In the techniques introduced in these documents, however, a period of charge from a rectifying circuit to a capacitor, and a period of discharge from the capacitor to the inverter are set alternately at each 1/4 of a cycle of an input AC voltage. For this reason, a magnitude of an output voltage remains at $1/\sqrt{2}$ times a crest value of the input AC voltage.

[0006] Further, an operation of the boost chopper is performed in a so-called non-continuous mode, and thus a peak current to flow in an inductor included in the boost chopper tends to be large.

[0007] It is, therefore, an object of the present invention to reduce a peak current to flow in an inductor included in a boost chopper. Further, it is another object of the present invention to provide a technique that makes an output voltage from a direct AC power converter higher than a conventional technique.

Means for Solving the Problems

[0008] A direct AC power converter of the present invention includes a DC link (7), a first rectifying circuit (5, 51), a boost chopper (3), and a switch (41).

[0009] The DC link has a first power supply line (L1), and a second power supply line (L2) to which an electric potential lower than an electric potential of the first power supply line is applied.

[0010] The first rectifying circuit has a plurality of input terminals into which an AC voltage is input, and a pair of output terminals (51c and 51d) each of which is connected to the DC link.

[0011] The inverter converts the voltage applied to the DC link into another AC voltage.

[0012] The boost chopper has a capacitor (34) at an output stage.

[0013] The switch performs discharge/non-discharge from the capacitor to the DC link.

[0014] In a first aspect of a direct AC power converter according to the present invention, charge into the capacitor is performed in the boost chopper at least at a first period that is a part of a period during which a discharge duty (d_c) is larger than 0.

5 [0015] The discharge duty is a time ratio at which the switch is conductive.

[0016] In a second aspect of the direct AC power converter according to the present invention, in the first aspect, the capacitor is charged in the boost chopper at the first period, and a part or entire of the period during which the discharge duty is 0.

[0017] In a third aspect of the direct AC power converter according to the present
10 invention, in any one of the first and second aspects, the capacitor (34) is charged/discharged by a charge power (P_{ci}) and a discharge power (P_{co}) at the first period, and the first period has a period during which the charge power is larger than the discharge power, and a period during which the discharge power is larger than the charge power.

15 [0018] In a fourth aspect of the direct AC power converter according to the present invention, in any one of the first to third aspects, a virtual DC link voltage (V_{dc}) is larger than $1/\sqrt{2}$ times the rectified voltage.

[0019] The virtual DC link voltage is expressed by a sum of a product ($d_c \cdot V_c$) of the discharge duty (d_c) and a voltage between both ends (V_c) of the capacitor (34), and a
20 product ($d_r \cdot V_{rec}$) of a rectifying duty (d_r) and a rectified voltage (V_{rec}) of the AC voltage.

[0020] The rectifying duty takes a value obtained by subtracting a sum of the discharge duty and a zero voltage duty (d_z) from 1.

[0021] The zero voltage duty is a time ratio for the inverter (6) to adopt a zero voltage
25 vector regardless of a magnitude of a voltage to be output from the inverter (6).

[0022] In a fifth aspect of the direct AC power converter according to the present invention, in any one of the first to fourth aspects, the discharge duty for that makes the zero voltage duty (d_z) minimum is set based on a command value (i_{rec}^*) of a rectified current (i_{rec}) being a sum of an electric current (i_b) flowing in the boost chopper (3) and an electric current (i_{direct}) flowing from the first rectifying circuit to the inverter (6), a command value (V_{dc}^*) of the virtual DC link voltage (V_{dc}), the voltage between both ends (V_c) of the capacitor, the rectified voltage (V_{rec}), and an electric current (i_{dc}) to be input into the inverter (6).

[0023] Desirably, when the virtual DC link voltage (V_{dc}) is larger than the rectified voltage (V_{rec}) and the command value (i_{rec}^*) of the rectified current (i_{rec}) is a predetermined value (dr_max) or more, the rectifying duty (dr) takes the predetermined value, and the discharge duty (dc) takes a value obtained by subtracting the predetermined value from 1.

[0024] The predetermined value is a value $((V_{dc}^* - V_c) / (V_{rec} - V_c))$ obtained by dividing a value obtained by subtracting the voltage between both ends (V_c) of the capacitor from the command value (V_{dc}^*) of a virtual DC link voltage (V_{dc}) by a value obtained by subtracting the voltage between both ends (V_c) from the rectified voltage (V_{rec}).

[0025] In a seventh aspect of the direct AC power converter according to the present invention, in any of the first to sixth aspects, further includes a second rectifying circuit (52) for inputting the rectified voltage (V_{rec}) into the boost chopper (3).

[0026] In an eighth aspect of the direct AC power converter according to the present invention, in any of the first to sixth aspects, the pair of output terminals of the first rectifying circuit is connected to an input side of the boost chopper.

[0027] In a ninth aspect of the direct AC power converter according to the present

invention, in any of the first to eighth aspects, the discharge duty (dc) is always positive.

[0028] A tenth aspect of the direct AC power converter according to the present invention, in any of the first to ninth aspects, further includes a diode parallel with the switch (41), the diode making a direction of charging the capacitor (34) from the DC link (7) being a forward direction.

Effects of the Invention

[0029] The capacitor is charged in the boost chopper at least at a part of the period during which the discharge duty is larger than 0, so that an average value of a maximum value of a voltage capable of being output from the inverter at a cycle of controlling the switching of the inverter can exceed $1/\sqrt{2}$ time a crest value of an AC voltage.

[0030] In another manner, even when the average value does not exceed $1/\sqrt{2}$ times the crest value of the AC voltage, a period of charging the capacitor can be set to be longer than the period in a conventional technique, thus, a peak value of an electric current to flow in an inductor included in the boost chopper can be reduced so as to be smaller than the value in a conventional technique.

[0031] Objects, features, aspects and advantages of the present invention will be apparent from the following detailed description taken in conjunction with the accompanying drawings.

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Brief Description of Drawings

[0032] [Fig. 1] A circuit diagram illustrating a configuration of a direct AC power converter according to this embodiment.

[Fig. 2] A circuit diagram illustrating another configuration of the direct AC power converter according to the embodiment.

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[Fig. 3] An an equivalent circuit of the direct AC power converter according to the embodiment.

[Fig. 4] A block diagram illustrating a configuration of a controller of direct AC power converter according to the embodiment.

5 [Fig. 5] A flowchart organizing steps of obtaining a rectifying duty, a zero voltage duty, a discharge duty, and a current command value.

[Fig. 6] A graph showing waveforms of specifications of a comparative example 1.

[Fig. 7] A graph showing waveforms of specifications of the comparative
10 example 1.

[Fig. 8] A graph showing waveforms of specifications of an example 1.

[Fig. 9] A graph showing waveforms of specifications of the example 1.

[Fig. 10] A graph showing waveforms of specifications of an example 2.

[Fig. 11] A graph showing waveforms of specifications of the example 2.

15 [Fig. 12] A graph showing waveforms of specifications of a comparative example 2.

[Fig. 13] A graph showing waveforms of specifications of the comparative example 2.

[Fig. 14] A graph showing waveforms of specifications of an example 3.

20 [Fig. 15] A graph showing waveforms of specifications of the example 3.

[Fig. 16] A graph showing waveforms of specifications of an example 4.

[Fig. 17] A graph showing waveforms of specifications of the example 4.

Description of Embodiments

25 [0033] Fig. 1 is a circuit diagram illustrating a configuration of a direct AC power

converter according to this embodiment.

[0034] The direct AC power converter includes a DC link 7, rectifying circuits 51 and 52, a boost chopper 3, a switch 41, and an inverter 6.

[0035] The DC link 7 has power supply lines L1 and L2. An electric potential lower
5 than an electric potential of the power supply line L1 is applied to the power supply line L2.

[0036] The rectifying circuit 51 has input terminals 51a and 51b that input an AC voltage V_{in} , and a pair of output terminals 51c and 51d to be connected to the power supply lines L1 and L2, respectively. The rectifying circuit 51 is of a full-wave
10 rectification type, and a case where it is formed by a diode bridge is illustrated here.

[0037] In Fig. 1, illustrated is a state where an AC voltage V_{in} is supplied to the rectifying circuit 51 from a single-phase AC power supply via a filter circuit 2. However, since the filter circuit 2 is provided in order to cut a harmonic noise, a cutoff frequency of the harmonic noise is higher than a frequency of the AC voltage V_{in} .
15 Since the operations of respective sections described below are hardly influenced by the function of the filter circuit 2, the description hereinafter excluding the operation of the filter circuit 2 is given.

[0038] An operation of a switch 41, and switching operations of a boost chopper 3 and an inverter 6 are controlled by a controller 9. It can be understood that the controller 9 is
20 also provided to the direct AC power converter.

[0039] The inverter 6 converts the voltage applied to the DC link 7 into another AC voltage. The inverter 6 is constituted so as to output a three-phase AC voltage to a permanent-magnet synchronous motor PMSM as an inductive load. The inverter 6 is a voltage inverter that operates under instantaneous spatial vector control, and can adopt a
25 publicly-known configuration. The inverter 6 outputs a three-phase current i_{inv} to the

permanent-magnet synchronous motor PMSM.

[0040] The boost chopper 3 has a capacitor 34 at an output stage thereof. More concretely, a rectified voltage V_{rec} of the AC voltage V_{in} is applied to the boost chopper 3. The rectified voltage is generated by the rectifying circuit 52 of a full-wave rectification type. A case where the rectifying circuit 52 is formed by the diode bridge is illustrated here.

[0041] The boost chopper 3 has an inductor 32, a switch 31, and a diode 33 besides the capacitor 34. The rectified voltage V_{rec} is applied between one end of the inductor 32 and one end of the switch 31. The other end of the inductor 32, the other end of the switch 31, and an anode of the diode 33 are connected to each other. The capacitor 34 is connected between a cathode of the diode 33 and the one end of the switch 31. For example, an insulated gate bipolar transistor is adopted as the switch 31.

[0042] Such a configuration is publicly known as the boost chopper, and thus its detailed operation is omitted.

[0043] However, it is noted that the switch 31 is conductive/non-conductive according to activity/non-activity of a control signal S_b , and that a boost duty d_b that is a time ratio of conductivity of the switch 31 is determined by a command value i_b^* of an electric current i_b (detailed later) to flow in the inductor 32, a capacitor voltage V_c to be applied to the capacitor 34, and the rectified voltage V_{rec} .

[0044] The switch 41 performs discharge/non-discharge from the capacitor 34 to the DC link 7 according to activity/non-activity of a control signal S_c . More concretely, the switch 41 is connected between the power supply lines L1 and L2 in series with respect to the capacitor 34.

[0045] Normally, the operation of the boost chopper 3 makes the capacitor voltage V_c higher than the rectified voltage V_{rec} . The switch 41, therefore, has a switch device for

controlling whether an electric current is allowed to flow from the boost chopper 3 (more concretely, from the capacitor 34) to the power supply line L1. For example, an insulated gate bipolar transistor is adopted as the switch device.

[0046] Further, a diode where a forward direction is a direction from the DC link 7 to the boost chopper 3 (more concretely, from the power supply line L1 to the capacitor 34) is desirably included in order to charge the capacitor 34 with a regenerated current from the inverter 6.

[0047] The controller 9 inputs the AC voltage V_{in} (more accurately, a signal indicating its waveform: the same applies hereafter), an electric current I_{inv} to be output from the inverter 6, and the capacitor voltage V_c , and outputs control signals S_b , S_c , and S_g . The control signal S_g is a signal for controlling switching of the inverter 6, and is composed of 6 ($= 3 \times 2$) signal groups because a case where the inverter 6 outputs a three-phase voltage is illustrated here.

[0048] Fig. 2 is a circuit diagram illustrating another configuration of the direct AC power converter according to this embodiment. In comparison with the configuration shown in Fig. 1, the rectifying circuit 51 concurrently serves as the rectifying circuit 52. That is to say, the pair of output terminals 51c and 51d of the rectifying circuit 5 is connected to an input side of the boost chopper 3. In this case, differently from the configuration shown in Fig. 1, the rectified voltage V_{rec} is not always applied to the boost chopper 3. This is because the other end of the inductor 32 is connected to the switch 41 via the power supply line L1, and the capacitor voltage V_c may be applied to the boost chopper 3 according to operating circumstances of the switch 41.

[0049] However, since both Fig. 1 and Fig. 2 are treated equivalently in an equivalent circuit described below, a control method described below is common. The equivalent circuit is first described below.

[0050] Fig. 3 is the equivalent circuit of the direct AC power converter shown in Fig. 1 and Fig. 2. The rectified voltage V_{rec} is expressed as a voltage source, and thus a switch G_{rec} indicates whether the rectifying circuit 51 is conductive or not. Further, the switches 31 and 41 are indicated by switches G_b and G_c , respectively. However, the regenerated current from the inverter 6 is not taken into consideration, and the diode of the switch 41 is not taken into consideration.

[0051] The inverter 6 and its load are expressed as current sources for flowing a DC current i_{dc} into the inverter 6. The inverter 6 is operated by a so-called zero voltage vector in a state that a switch G_z is conductive. When the inverter 6 is operated by the zero voltage vector, the inverter 6 short-circuits with respect to an inductive load with any one of the power supply lines L1 and L2, and thus does not receive an electric current from the DC link 7.

[0052] On the other hand, the inverter 6 is allowed to be operated by any vectors other than the zero voltage vector when the inverter 6 receives an electric current from the DC link 7. Therefore, the inverter 6 is operated by any vectors other than the zero voltage vector when the switch G_z is non-conductive.

[0053] When the capacitor voltage V_c higher than the rectified voltage V_{rec} is applied to the DC link 7, an electric current does not flow in the DC link 7 from the rectifying circuit 51. That is to say, when the switch G_c is conductive, the switch G_{rec} is not conductive.

[0054] As described in the Patent Documents 1 and 2, when time ratios of the conductivity of the switches G_{rec} , G_c , and G_z are a rectifying duty d_r , a discharge duty d_c , and a zero voltage duty d_z , respectively, a sum of these three is 1. That is to say, the following formula (1) holds. These time ratios are time ratios in a shorter cycle than a cycle of the AC voltage V_{in} , and time ratios relating to a carrier cycle controlled with

approximation that the AC voltage V_{in} is constant.

[0055] $d_r + d_c + d_z = 1 \dots (1).$

[0056] The zero voltage duty d_z is a time ratio corresponding to a period during which the inverter 6 adopts the zero voltage vector regardless of a magnitude of a voltage to be
5 output. Further, the discharge duty d_c is a time ratio of the conductivity of the switch 41.

[0057] The rectifying duty d_r is a time ratio of the conductivity of the rectifying circuit 51, and it is found from the formula (1) that it takes a value obtained by subtracting a sum of the discharge duty d_c and the zero voltage duty d_z from 1.

10 [0058] When the switch 41 is conductive, the capacitor voltage V_c is adopted, and when the switch 41 is not conductive, the rectified voltage V_{rec} is adopted as the DC voltage to be applied to the DC link 7. Therefore, a virtual voltage (in this application, “a virtual DC link voltage”) V_{dc} is determined according to the following formula (2).

[0059] $V_{dc} = d_r \cdot V_{rec} + d_c \cdot V_c \dots (2).$

15 [0060] That is to say, the virtual DC link voltage V_{dc} is expressed by a sum of a product ($d_c \cdot V_c$) of the discharge duty d_c and the capacitor voltage V_c , and a product ($d_r \cdot V_{rec}$) of the rectifying duty d_r and the rectified voltage V_{rec} . This can be understood as an average of maximum values of voltages capable of being output from the inverter 6 in a cycle of control of a switching operation on the switch 41 or the
20 inverter 6. Fig. 3 shows the virtual DC link voltage V_{dc} as a voltage to be generated at both ends of a current source i_{dc} (this causes the DC current i_{dc} to flow) representing the inverter 6 and the load of the inverter 6.

[0061] In such an equivalent circuit, an electric current from the voltage source indicating the rectified voltage V_{rec} (in this application, “a rectified current”) i_{rec} is
25 understood as a sum of the electric current i_b to flow in the inductor 32 (included in the

boost chopper 3) and an electric current i_{direct} to flow from the rectifying circuit 51 into the inverter 6 in the actual configuration.

[0062] In the configuration shown in Fig. 1, the rectified current i_{rec} is not directly indicated. In Fig. 1, the electric current i_{direct} is an electric current that flows from the rectifying circuit 51 into the DC link 7, and the electric current i_b is an electric current that flows from the rectifying circuit 52 into the boost chopper 3.

[0063] On the other hand, in a configuration shown in Fig. 2, the rectified current i_{rec} is output from the output terminal 51c, and a part thereof to flow into the inductor 32 becomes the electric current i_b .

10 [0064] Since the switch G_{rec} indicates the conductivity/non-conductivity of the rectifying circuit 51, the rectifying duty d_r that is the time ratio of the conductivity is expressed as a value obtained by dividing the electric current i_{direct} by the DC current i_{dc} . Therefore, the following formula (3) holds.

[0065] $i_{rec} = d_r \cdot i_{dc} + i_b \dots (3)$.

15 [0066] In the Patent Documents 1 and 2, and Non-Patent Document 1, a period during which the electric current i_b is allowed to flow is excluded from a period (providing period) during which an electric power is provided from the capacitor 34 to the DC link 7. Furthermore, the providing period and a period during which the capacitor 34 receives the electric power from the DC link 7 (receiving period) are set alternately in each 1/4 of the cycle of the AC voltage V_{in} . For this reason, the virtual DC link voltage V_{dc} does not exceed $1/\sqrt{2}$ times a crest value of the AC voltage.

[0067] However, even at the providing period, the capacitor 34 does not always perform the discharge, and is conductive at the discharge duty d_c . Therefore, a period during which the capacitor 34 can be charged is included even in the providing period.

25 On the other hand, the providing period is necessary in a period during which the virtual

DC link voltage V_{dc} is larger than the rectified voltage V_{rec} . This is because that, even with $dc = 0$, as is clear from the formula (2), the virtual DC link voltage V_{dc} can be determined only by the rectified voltage V_{rec} , the rectifying duty dr , and the zero voltage duty dz with $dz > 0$ when the virtual DC link voltage V_{dc} is smaller than the rectified voltage V_{rec} .

[0068] In other words, on at least a part of the period during which the virtual DC link voltage V_{dc} is larger than the rectified voltage V_{rec} ($dc > 0$ at this period: a reason for this is described later), the capacitor 34 is charged in the boost chopper 3 so that the capacitor 34 is supplemented with an electric power. As a result, the virtual DC link voltage V_{dc} can exceed $1/\sqrt{2}$ times the crest value of the AC voltage V_{in} . Needless to say, at a part or entire of the period during which $dc = 0$, the capacitor 34 can be charged.

[0069] In another manner, even when the virtual DC link voltage V_{dc} does not exceed $1/\sqrt{2}$ times the crest value of the AC voltage V_{in} , the period during which the capacitor 34 is charged can be set to be longer than a period in a conventional technique, thus, a peak value of the electric current i_b to flow in the inductor 32 can be reduced to be lower comparing to the conventional technique.

[0070] Further details are described below. In order to reduce a loss in the boost chopper 3 and a rated current required by the inductor 32, it is desirable to reduce the discharge duty dc .

[0071] A case where the rectified current i_{rec} is larger than the electric current i_{direct} is first considered. According to the formula (3), this is a case where a margin exist for flowing the electric current i_b in the boost chopper 3, and a magnitude of the rectifying duty dr is not limited by the rectified current i_{rec} . In this case, a case where the virtual DC link voltage V_{dc} is made to be the rectified voltage V_{rec} or less is further considered as a first case. The first case is realized so that $dc = 0$, and $dz > 0$. Concretely, when

$dc = 0$ in the formulas (1) and (2), the rectifying duty dr and the zero voltage duty dz in the first case are determined by the following formula (4). At this time, the capacitor 34 is not discharged via the switch 41.

$$[0072] \quad dr = V_{dc}/V_{rec}, dz = 1 - V_{dc}/V_{rec} \dots (4).$$

5 [0073] In other words, when a command value V_{dc}^* of the virtual DC link voltage V_{dc} is set, the rectifying duty dr should be set to a ratio of the command value V_{dc}^* to the rectified voltage V_{rec} (V_{dc}^*/V_{rec}), and the zero voltage duty dz should be set to a value obtained by subtracting the ratio from 1 in order to make the virtual DC link voltage V_{dc} follow the command value V_{dc}^* with the discharge duty dc being zero in the first
10 case.

[0074] Further, it is found that the zero voltage duty dz also becomes minimum here. This is because in order to match the virtual DC link voltage V_{dc} with the command value V_{dc}^* even when the discharge duty dc increases, the zero voltage duty dz has to be increased according to the formula (2).

15 [0075] In other words, in the first case, it can be also grasped that to set the rectifying duty dr to the ratio (V_{dc}^*/V_{rec}) means to set the discharge duty dc for making the zero voltage duty dz minimum and to set that value to 0.

[0076] When the above control is made in the first case, the capacitor 34 is not discharged.

20 [0077] A case where the rectified current i_{rec} is larger than the electric current i_{direct} and the virtual DC link voltage V_{dc} is larger than the rectified voltage V_{rec} is considered as a second case. In this case, it is obvious from the formula (2) that the discharge from the capacitor 34 to the DC link 7 has to be performed. That is to say, the discharge duty dc is set positive. It is also obvious from the formula (2) that the virtual DC link voltage
25 V_{dc} has to be the capacitor voltage V_c or less.

[0078] The zero voltage duty d_z that does not contribute to a rise in the virtual DC link voltage V_{dc} is necessary to be reduced in order to reduce the discharge duty d_c so that the loss and the rated current are reduced. In the second case, similarly to the first case, since the magnitude of the rectifying duty d_r is not limited by the rectified current i_{rec} ,
 5 the DC current i_{dc} can be fed by the rectified current i_{rec} . Therefore, the zero voltage duty d_z can be reduced to zero.

[0079] According to this and the formula (1), the formula (2) can be deformed into the following formula (5).

$$[0080] \quad V_{dc} = d_r \cdot V_{rec} + (1 - d_r) \cdot V_c$$

$$10 \quad \therefore d_r = (V_{dc} - V_c) / (V_{rec} - V_c) \dots (5).$$

[0081] In other words, it is found that in order to make the virtual DC link voltage V_{dc} follow the command value V_{dc}^* in the second case, the rectifying duty d_r should be set to a ratio $(V_{dc}^* - V_c) / (V_{rec} - V_c)$, and the discharge duty d_c should be set to a value obtained by subtracting the ratio from 1.

15 [0082] In the second case, it can be also grasped that to set the rectifying duty d_r in the above manner means to set the discharge duty d_c for making the zero voltage duty d_z minimum and to set its value to $(1 - d_r)$. This is because the zero voltage duty d_z reduces to zero also in this case.

[0083] It can be grasped that the control of the each duty means to set the discharge
 20 duty d_c for making the zero voltage duty d_z minimum based on two viewpoints. The first viewpoint is whether the rectified current i_{rec} is larger than the electric current i_{direct} or not, namely, whether a command value i_{rec}^* of the rectified current i_{rec} is set to be larger than an electric current i_{rect} or not. The second viewpoint is whether the virtual DC link voltage V_{dc} is larger than the rectified voltage V_{rec} or not, namely,
 25 whether the command value V_{dc}^* is larger than the rectified voltage V_{rec} or not.

[0084] There is a margin for flowing the electric current i_b from the rectifying circuit 52 in the circuit shown in Fig. 1, and from the rectifying circuit 51 in the circuit shown in Fig. 2 respectively. Therefore, when the DC current i_{dc} is estimated, with an estimated value i_{dc}^* , the command value i_b^* of the electric current i_b is set according to the following formula (6) in consideration of the formula (3).

[0085] $i_b^* = i_{rec} \cdot dr_{max} \cdot i_{dc}^* \dots (6)$.

[0086] Here, dr_{max} indicates the rectifying duty dr respectively expressed by the formula (4) in the first case and the formula (5) in the second case.

[0087] Particularly like the second case, when the virtual DC link voltage V_{dc} is larger than the rectified voltage V_{rec} , it becomes the providing period during which the discharge is performed from the capacitor 34 to the DC link 7 at the discharge duty dc . Not only the discharge but also the charge of the capacitor 34 is performed by flowing of the electric current i_b according to the command value i_b^* expressed by the formula (6) at the providing period.

[0088] In this application, therefore, a period corresponding to the second case is called "charge/discharge zone". On the contrary, a period corresponding to the first case is called "charge zone" in this application because not the discharge but only the charge of the capacitor 34 is performed.

[0089] A publicly-known method can be employed for a switching operation to be performed by a switch G_b (switch 31) using the electric current i_b flowing in the boost chopper 3 to charge the capacitor 34 to the capacitor voltage V_c . This method may be a so-called current discontinuous mode, or a critical mode, or a current continuous mode.

[0090] A case where the rectified current i_{rec} is the electric current i_{direct} or less is considered as a third case. With reference to the formula (3), it is a case where a margin of flowing the electric current i_b cannot exit. Or the case, with reference to the formula

(6), where $ib^* < 0$, namely, the following formula (7) holds.

[0091] $irec^* < dr_max \cdot idc^{\wedge} \dots (7).$

[0092] Since the electric current ib does not actually take a negative value, however, the rectifying duty dr that takes a value smaller than dr_max is adopted under a condition
 5 of the formula (7), so that the formula (3) is made to hold under conditions where $irec \geq 0$, $dr \geq 0$, $idc > 0$, and $ib \geq 0$.

[0093] The command value ib^* of the electric current ib is set to 0 so that $ib \geq 0$ at all times. That is to say, at a period during which the formula (7) holds, the capacitor 34 is not charged, and the capacitor 34 is discharged by the discharge duty dc determined
 10 below. In this application, therefore, the period during which the formula (7) holds is called “discharge zone”.

[0094] The rectifying duty dr is determined by using a command value $irec^*$ and the estimated value $idc^{\wedge}$ according to the following formula (8) in consideration of the formula (7).

15 [0095] $dr = irec^* / idc^{\wedge} \dots (8).$

[0096] That is to say, in order to make the virtual DC link voltage V_{dc} follow the command value V_{dc}^* , the rectifying duty dr comes to be set to a ratio ($irec^* / idc^{\wedge}$) of the command value $irec^*$ to the estimated value $idc^{\wedge}$.

[0097] The following formula (9) has to hold in consideration of the formula (2) in
 20 order to make the virtual DC link voltage V_{dc} follow the command value V_{dc}^* .

[0098] $V_{dc}^* = dr \cdot V_{rec} + dc \cdot V_c \dots (9).$

[0099] There, the rectifying duty dr is set to a value set by the formula (8), and the capacitor voltage V_c is actually fixed. Therefore, parameters that can be selected for making a right side of the formula (9) equal to the given command value V_{dc}^* are the
 25 zero voltage duty dz and the discharge duty dc .

[0100] The discharge duty dc is determined according to the following formula (10) directly led from the formula (9).

[0101] $dc = (V_{dc} - dr \cdot V_{rec}) / V_c \dots (10)$.

[0102] It is noted that the capacitor voltage V_c technically comes to reduce at the
 5 period during which the formula (7) holds ("discharge period"). This is because the command value ib^* is set to 0 as described above. However, appropriate setting of the command value $irec^*$ enables the discharge period to be shortened to an extent where the reduction in the capacitor voltage V_c can be ignored.

[0103] In Patent Documents 1 and 2 and Non-Patent Document 1, since the rectified
 10 current $irec$ has a waveform of full-wave rectification, such selection of the command value $irec^*$ was not considered. However, in this embodiment, since the rectified current $irec$ is not limited to the waveform of the full-wave rectification, the discharge period is shortened and the discharge duty dc can be set with the formula (10) wherein the capacitor voltage V_c is constant.

15 [0104] Additionally, since a restricting condition of the formula (1) is present, the zero voltage duty dz comes to be obtained by the following formula (11).

[0105] $dz = 1 - dr - dc \dots (11)$.

[0106] As is seen above, at the discharge period, when the command value $irec^*$ and the estimated value $idc^{\wedge}$ are obtained, the rectifying duty dr is determined according to
 20 the formula (8), and further, the discharge duty dc and the zero voltage duty dz are uniquely determined according to the formulas (10) and (11), respectively.

[0107] That is to say, being not allowed to take a value not less than the value determined according to the formula (11), the zero voltage duty dz is set to a minimum value thereof. That is to say, it can be grasped that the discharge duty dc for making the
 25 zero voltage duty dz minimum is set also in the discharge zone, similarly to the charge

zone and the charge/discharge zone.

[0108] When the rectifying duty d_r , the zero voltage duty d_z , the discharge duty d_c , and the command value i_b^* are determined in the above manner, the control signals S_b , S_c , and S_g can be generated by using a publicly-known technique.

5 [0109] Fig. 4 is a block diagram illustrating a configuration of the controller 9. The controller 9 is roughly divided into a current command generator 91, a DC current estimator 92, a duty divider 93, a pulse width modulation signal generator 94, and a chopper signal generator 95.

[0110] The current command generator 91 generates the command value i_{rec}^* of the
10 rectified current i_{rec} . As detailed later, Fig. 4 illustrates a configuration where the command value i_{rec}^* has an absolute value of a sinusoidal wave form, but the command value i_{rec}^* is not always limited to provision of such a waveform.

[0111] The DC current estimator 92 obtains the estimated value $\hat{i}_{dc}$ of the DC current i_{dc} . As is understood from the equivalent circuit of Fig. 3, a portion that can actually
15 measure the DC current i_{dc} is not present in an actual circuit. Therefore, the estimated value $\hat{i}_{dc}$ is adopted in the calculation expressed by the formulas (6) and (8).

[0112] The DC current i_{dc} and the virtual DC link voltage V_{dc} enables obtaining of an electric power to be output from the inverter 6 in the equivalent circuit. On the other hand, an electric power to be output from the inverter 6 in the actual circuit is obtained by
20 the three-phase electric current i_{inv} and a three-phase voltage V_{inv} to be output from the inverter 6. Therefore, theoretically the estimated value $\hat{i}_{dc}$ can be obtained from the virtual DC link voltage V_{dc} , the electric current i_{inv} , and a voltage V_{inv} .

[0113] It is noted that the voltage V_{inv} to be output from the inverter 6 is controlled by the pulse width modulation signal generator 94 so as to follow its command value V_{inv}^* .
25 Further, the virtual DC link voltage V_{dc} itself cannot be measured, but is controlled by

the duty divider 93 so as to follow the command value V_{dc}^* . On the other hand, the electric current I_{inv} can be measured from wire connection between the inverter 6 and the permanent-magnet synchronous motor PMSM. In this embodiment, therefore, the estimated value $\hat{i}_{dc}$ is obtained from the command values V_{dc}^* and V_{inv}^* , and the electric current I_{inv} . Naturally, the estimated value $\hat{i}_{dc}$ may be obtained by another method.

[0114] The duty divider 93 determines the rectifying duty d_r , the zero voltage duty d_z , the discharge duty d_c , and the command value i_b^* according to the methods described in the first to third cases based on the command values V_{dc}^* and i_{rec}^* , the capacitor voltage V_c , the rectified voltage V_{rec} , and the estimated value $\hat{i}_{dc}$. The expression “duty ‘divider’” is given here because as expressed by the formula (2), the value 1 is divided by the rectifying duty d_r , the zero voltage duty d_z , and the discharge duty d_c .

[0115] The pulse width modulation signal generator 94 generates the control signals S_c and S_g based on the rectifying duty d_r , the zero voltage duty d_z , the discharge duty d_c , and the command value V_{inv}^* and V_{dc}^* . For example, these duties and respective phase parts of the command value V_{inv}^* are operated so that signal waves are generated, and comparing the signal waves and a triangular wave carrier enables to generate the control signals S_c and S_g . Since such a method is publicly known, and is described in, for example, Patent Documents 1 and 2, detailed description is omitted.

[0116] The chopper signal generator 95 has a boost chopper duty arithmetic unit 951 and a pulse width modulation signal generator 952. The boost chopper duty arithmetic unit 951 determines the boost duty d_b based on the command value i_b^* , the capacitor voltage V_c , and the rectified voltage V_{rec} .

[0117] A method for determining the boost duty d_b varies depending on a mode that operates the boost chopper 3. As this method, however, a normal method for

determining the discharge duty of the boost chopper can be adopted, and thus detailed description is omitted.

[0118] The pulse width modulation signal generator 952 can also generate the control signal S_b based on the boost duty d_b according to a publicly-known modulation method.

5 [0119] A configuration of the current command generator 91 is described below. The current command generator 91 has an output power estimator 911, a trigonometric function value generator 912, a capacitor voltage controller 913, an adder 914, a multiplier 915, and a divider 916.

[0120] The output power estimator 911 obtains an estimated value $P_{out}^{\wedge}$ of an output
10 power P_{out} based on the command value V_{inv}^* and the electric current i_{inv} . Obtaining the estimated value $i_{dc}^{\wedge}$ in the above manner, the DC current estimator 92 may receive the estimated value $P_{out}^{\wedge}$ obtained from the output power estimator 911 and the command value V_{dc}^* so as to obtain the estimated value $i_{dc}^{\wedge}$.

[0121] The capacitor voltage controller 913 obtains a deviation $V_c^* - V_c$, which is
15 output to the adder 914 after being provided with at least proportional control, between the capacitor voltage V_c and its command value V_c^* .

[0122] The adder 914 adds an output from the capacitor voltage controller 913 to the estimated value $P_{out}^{\wedge}$. This is a process for suitably setting a command value P_{in}^* of the input power by correcting the estimated value $P_{out}^{\wedge}$ so as to be larger/smaller when
20 the capacitor voltage V_c becomes smaller/larger than the command value V_c^* respectively, so as to reduce the deviation. As the capacitor voltage controller 913, not merely proportional control as it is but proportional-integral control, or proportional-integral-derivative control is desirably adopted for stability of the deviation.

[0123] Here is assumed the case where the command value i_{rec}^* of the rectified
25 current i_{rec} takes an absolute value of the sinusoidal waveform, and the rectified voltage

Vrec takes the absolute value of the sinusoidal waveform, thus an output from the adder 914 is multiplied by a trigonometric function value $2 \cdot \sin^2 \theta$ so that the command value Pin^* is obtained.

[0124] The trigonometric function value generator 912 generates the trigonometric function value $2 \cdot \sin^2 \theta$ based on a phase angle θ of the power-supply voltage. The multiplier 915 multiplies an added result of the adder 914 and trigonometric function value $2 \cdot \sin^2 \theta$ so as to obtain the command value Pin^* .

[0125] Since an input power Pin is a product of the rectified voltage V_{rec} and the rectified current i_{rec} , the command value i_{rec}^* of the rectified current i_{rec} is obtained by dividing the command value Pin^* by the rectified voltage V_{rec} .

[0126] The phase angle θ is estimated from, for example, the measured voltage V_{in} by a power-supply phase estimator 96. The power-supply phase estimator 96 can be constituted by, for example, a phase locked loop. The rectified voltage V_{rec} can be obtained in, for example such a manner that an absolute value circuit 97 obtains an absolute value of the measured voltage V_{in} . Since concrete configurations of the power-supply phase estimator 96 and the absolute value circuit 97 are publicly-known techniques, details are not described.

[0127] Fig. 5 is a flowchart organizing steps of obtaining the rectifying duty d_r , the zero voltage duty d_z , the discharge duty d_c , and the command value i_b^* . It is grasped that this flowchart shows an operation of the duty divider 93.

[0128] Step S101 corresponds to a determination whether the operation of the direct AC power converter corresponds to the first case or the second case if it does not correspond to the third case. The determination is made at step S101 whether the command value V_{dc}^* of the virtual DC link voltage V_{dc} is the rectified voltage V_{rec} or less. The process goes to steps S102 and S104 when the determination is affirmative,

steps S103 and S105 when negative, respectively.

[0129] Steps S102 and S104 are processes for determining whether the operation of the direct AC power converter corresponds to the first case or the third case. In consideration of the formula (4), $dr_max = V_{dc}^*/V_{rec}$ is obtained at step S102. A determination is made at step S104 whether or not the command value $irec^*$ is a value $dr_max \cdot idc^*$ or more in consideration of the formula (7). When the determination at step S104 is affirmative, the operation of the direct AC power converter corresponds to the first case, and the process goes to steps S106 and S109. When the determination at step S104 is negative, the operation of the direct AC power converter corresponds to the third case, and the process goes to steps S108 and S110.

[0130] Steps S103 and S105 are processes for determining whether the operation of the direct AC power converter corresponds to the second case or the third case. In consideration of the formula (5), $dr_max = (V_{dc}^* - V_c)/(V_{rec} - V_c)$ is obtained at step S103. A determination is made at step S105 whether or not the command value $irec^*$ is the value $dr_max \cdot idc^*$ or more in consideration of the formula (7) similarly to step S104. When the determination at step S105 is affirmative, the operation of the direct AC power converter corresponds to the second case, and the process goes to steps S107 and S109. When the determination at step S105 is negative, the operation of the direct AC power converter corresponds to the third case, and the process goes to steps S108 and S110.

[0131] Steps S106, S107 and S108 are setting each duty according to the first case, the second case, and the third case, respectively. The step S109 is setting of the command value ib^* according to the first case and the second case, and step S110 is setting of the command value ib^* according to the third case. These setting contents are as described above.

[0132] When $V_{dc} > V_{rec}$, any of steps S107 and S108 is executed according to the

determined result at step S101. When step S107 is executed, the discharge duty d_c takes a value $(1 - d_r)$. In this case, the rectifying duty d_r is expressed by the formula (5), and is smaller than 1. In this case, therefore, the discharge duty d_c is larger than 0.

[0133] Or, when step S108 is executed, the discharge duty d_c takes a value expressed
 5 by the formula (10). When $V_{dc} > V_{rec}$, a numerator of a right side of the formula (10) is larger than 0 regardless of the value of the rectifying duty d_r . Also in this case, therefore, the discharge duty d_c is larger than 0.

[0134] That is to say, when $V_{dc} > V_{rec}$, the setting is always such that $d_c > 0$.

[0135] The controller 9 can be realized by including, for example, a microcomputer
 10 and a storage device. The microcomputer executes the respective processing steps (in other words, the procedure) described in a program. The storage device can be configured by, for example, one of or a plurality of various storage devices such as a ROM (Read Only Memory), a RAM (Random Access Memory), rewritable non-volatile memory (such as an Erasable Programmable ROM (EPROM)), and a hard disc device.
 15 The storage device stores various information and data etc., and stores a program to be executed by the microcomputer, and provides a work area for executing the program. It is noted that the microcomputer can be grasped to function as various means corresponding to the respective processing steps described in the program, or can be grasped to realize various functions corresponding to the respective processing steps.
 20 Further, the controller 9 is not limited to this, and thus some of or entire of various procedures (obtaining respective measured values, executing steps S101 to S110 etc.) to be executed by the controller 9, or respective elements composing those, or various functions may be realized by hardware.

[0136] << Examples >>

25 Examples expressing the effects of the use of the above methods are described

below.

[0137] In the above Patent Documents 1 and 2, and Non-Patent Document 1, the following conditions are satisfied:

(i) the period during which the electric current i_b flows is excluded from the providing
 5 period during which an electric power is provided from the capacitor 34 to the DC link 7;
 and

(ii) the receiving period during which the capacitor 34 receives the electric power from the DC link 7 and the providing period are set alternately in each $1/4$ of the cycle of the AC voltage V_{in} .

10 [0138] When the rectified current i_{rec} is allowed to be distorted from a sinusoidal waveform with the conditions (i) and (ii) being satisfied, a peak current of the electric current i_b can be reduced to be lower than the peak current in a case where it is not allowed. This is because a change in the electric current i_b at the receiving period should be reduced.

15 [0139] Fig. 6 and Fig. 7 are graphs showing waveforms of specifications in a case where the peak current of the electric current i_b is reduced while the above conditions (i) and (ii) are maintained by simulation (“comparative example 1”). It is noted that the virtual DC link voltage V_{dc} is set to $1/\sqrt{2}$ (212 V) of a crest value (300 V) of the rectified voltage V_{rec} . Further, the capacitor voltage V_c is higher than the rectified voltage V_{rec}
 20 and is constant (400 V) (the same shall apply hereafter).

[0140] Further, in order to ensure consistency with respect to the embodiment, the providing period and the receiving period are not adopted but “charge” and “discharge” are described on a horizontal axis. Here, “discharge” means the period during which the capacitor 34 can be charged, and “discharge” means the period during which the capacitor
 25 34 can be discharged. Further, the electric current i_b does not flow at the “discharge”

period according to the above condition (i). Further, “charge” and “discharge” are $1/4$ (90°) of the cycle of the AC voltage V_{in} according to the condition (ii).

[0141] A first row in Fig. 6 shows waveforms of the capacitor voltage V_c , the rectified voltage V_{rec} , and the virtual DC link voltage V_{dc} (this is assumed to accurately follow the command value V_{dc}^* . The same shall apply hereafter).

[0142] A second row in Fig. 6 shows waveforms of the rectified current i_{rec} (this is assumed to accurately follow the command value i_{rec}^* . The same shall apply hereafter), and the DC current i_{dc} (this is assumed to be accurately estimated by the estimated value $i_{dc}^\wedge$. The same shall apply hereafter). When the DC current i_{dc} is made to be constant, in cooperation with the virtual DC link voltage V_{dc} that takes a constant value, the output power P_{out} becomes constant.

[0143] A third row in Fig. 6 shows waveforms of the rectified current i_{rec} , the electric current i_{direct} (this is obtained by a product of the rectifying duty d_r and the estimated value $i_{dc}^\wedge$. The same shall apply hereafter.), and the electric current i_b (this is assumed to accurately follow the command value i_b^* . The same shall apply hereafter).

[0144] A fourth row in Fig. 6 shows waveforms of the rectifying duty d_r , the discharge duty d_c , and the zero voltage duty d_z .

[0145] A fifth row in Fig. 6 shows waveforms of the DC current i_{dc} , the electric current i_{direct} , an electric current i_c to flow from the capacitor 34 to the DC link 7 (this is obtained by a product of the discharge duty d_c and the estimated value $i_{dc}^\wedge$. The same shall apply hereafter.), a zero-phase current i_z (this is obtained by a product of the zero voltage duty d_z and the estimated value $i_{dc}^\wedge$. The same shall apply hereafter).

[0146] A first row in Fig. 7 shows waveforms of an electric power P_{out} to be output from the inverter 6 (this is assumed to be accurately estimated based on the estimated value $P_{out}^\wedge$. The same shall apply hereafter.), an electric power P_{direct} to be

determined based on the rectified voltage V_{rec} and the electric current i_{direct} , an electric power P_{co} to be discharged from the capacitor 34, and an electric power P_c to be input/output into/from the capacitor 34. The electric power P_c takes a negative value because it reduces the electric power P_{out} is reduced at a charge time, and it matches with
 5 the electric power P_{co} at a discharge time.

[0147] A second row in Fig. 7 shows waveforms of the input power P_{in} (this is assumed to accurately follow the command value P_{in}^* . The same shall apply hereafter.), the electric power P_{direct} , an electric power P_{ci} with which the capacitor 34 is charged, and the electric power P_c . The electric power P_c has the same absolute value as that of
 10 the electric power P_{ci} at the charge time.

[0148] A third row in Fig. 7 shows a graph where the electric powers P_c , P_{ci} , and P_{co} relating to the capacitor 34 are extracted from the first and second rows in Fig. 7 so as to be brought together.

[0149] When a peak of the electric current i_b is reduced as that, its peak value is 44%
 15 (11.6A) of the crest value of the electric current to flow from the single-phase AC power supply (input current). In order to reduce a change in the electric current i_b , the rectified current i_{rec} is planarized at the “charge” period, and is considerably distorted from the sinusoidal waveform.

[0150] Further, a power current abruptly changes, thus it may be said that the
 20 waveform is not practically preferable from a viewpoint of a power-supply noise and resonance of a filter circuit. When the abrupt change in the power current is suppressed, namely, when the rectified current i_{rec} , which changes continuously and whose value becomes 0 when a power voltage is zero cross, is made to flow, the peak value of the electric current i_b becomes larger.

25 [0151] On the contrary, when the virtual DC link voltage V_{dc} is larger than the

rectified voltage V_{rec} , not only the discharge but also the charge are performed on the capacitor 34, so that the peak current of the electric current i_b can be further suppressed by using the method according to this embodiment.

[0152] Fig. 8 and Fig. 9 are graphs showing waveforms of specifications in a case where control is made by simulation according to the method of this embodiment (“example 1”). Fig. 8 and Fig. 9 show waveforms of the specifications corresponding to Fig. 6 and Fig. 7 respectively. It is noted that the virtual DC link voltage V_{dc} and the electric current i_{dc} are equal to cases described with Fig. 6 and Fig. 7, and are set to 212 V and 21.2 A, respectively. Further, the crest value of the rectified voltage V_{rec} is also set to 300 V.

[0153] The charge is performed but the discharge is not performed on the capacitor 34 at the “charge” period in the graphs of Fig. 8 and Fig. 9 ($P_{ci} > 0$, $P_{co} = 0$). Concretely, the “charge” period is a period during which the virtual DC link voltage V_{dc} is the rectified voltage V_{rec} or less, $i_c = 0$ (namely, $d_c = 0$), and steps S106 and S109 in Fig. 5 are executed. Further, the discharge is performed but the charge is not performed on the capacitor 34 at the “discharge” period ($P_{co} > 0$, $P_{ci} = 0$). Concretely, the “discharge” period is a period during which the virtual DC link voltage V_{dc} is larger than the rectified voltage V_{rec} , $i_z > 0$ (namely, $d_z > 0$), and steps S108 and S110 in Fig. 5 are executed. And, the “charge/discharge” period is a period during which the virtual DC link voltage V_{dc} is larger than the rectified voltage V_{rec} , $i_z = 0$ (namely, $d_z = 0$), and steps S107 and S109 in Fig. 5 are executed. The “charge/discharge” period includes a period during which the electric power P_{ci} for charging the capacitor 34 is larger than the electric power P_{co} to be discharged from the capacitor 34 (namely, the period during which $P_c < 0$: this is adjacent to the “charge” period, and is separated from the “discharge” period), and a period during which the electric power P_{co} to be discharged from the capacitor 34 is

larger than the electric power P_{ci} for charging the capacitor 34 (namely, the period during which $P_c > 0$; this is adjacent to the “discharge” period and is separated from the “charge” period).

[0154] When the peak of the electric current i_b is reduced, the peak value is 40% (10.0 A) of the crest value of the electric current to flow from the single-phase AC power supply.

[0155] In the example 1, the provision of the “charge/discharge” period enables the peak of the electric current i_b to be reduced so as to be lower than that in the comparative example 1.

[0156] Even in the case shown in Fig. 8 and Fig. 9, however, since the virtual DC link voltage V_{dc} is $1/\sqrt{2}$ of the crest value of the rectified voltage V_{rec} , the “charge” periods match with those in the case shown in Fig. 6 and Fig. 7. Therefore, the limitation of the condition (i) is eliminated so that the virtual DC link voltage V_{dc} can be set so as to be higher than $1/\sqrt{2}$ of the crest value of the rectified voltage V_{rec} .

[0157] Fig. 10 and Fig. 11 are graphs showing waveforms of specifications in a case where the control is made by simulation according to the method in this embodiment (“example 2”). Waveforms of the specifications corresponding to Fig. 8 and Fig. 9 are respectively shown. It is noted that a case is shown where the crest value of the rectified voltage V_{rec} is set to 300 V similarly to Fig. 6 to Fig. 9, but the virtual DC link voltage V_{dc} is set to 0.8 (240 V) times the crest value of the rectified voltage V_{rec} .

[0158] By setting the “charge” period shorter and the “charge/discharge” period longer, a ratio of the virtual DC link voltage V_{dc} to the crest value of the rectified voltage V_{rec} can be heightened. The “charge” period correspond to steps S106 and S109 in Fig. 5, the “discharge” period corresponds to steps S108 and S110 in Fig. 5, and the “charge/discharge” period corresponds to steps S107 and S109 in Fig. 5. In this case,

the crest value of the input current is 27.0 A, and the electric current i_b is 12.0 A.

[0159] Even when the limitation of the condition (i) is not removed but only a limitation of the condition (ii) is removed, the ratio of the virtual DC link voltage V_{dc} to the crest value of the rectified voltage V_{rec} can be heightened. Fig. 12 and Fig. 13 are graphs showing waveforms of specifications in a case where the peak current of the electric current i_b is reduced by simulation without providing the “charge/discharge” period (“comparative example 2”). Waveforms of specifications corresponding to Fig. 6 and Fig. 7 are respectively shown. It is noted that the crest value of the rectified voltage V_{rec} is set to 300 V similarly to Fig. 10 and Fig. 11, and the virtual DC link voltage V_{dc} is set to 0.8 (240 V) times the crest value of the rectified voltage V_{rec} .

[0160] By setting the “charge” period shorter and the “discharge” period longer, the ratio of the virtual DC link voltage V_{dc} to the crest value of the rectified voltage V_{rec} can be heightened. However, when the period during which the electric current i_b flows is limited to the “charge” period, the peak value of the electric current i_b naturally rises. The peak value of the electric current i_b , here, comes to 15.3 A, and the crest value of the input current comes to 30.3 A. These are all larger than the case described in the example 2. Naturally, in the comparative example 2, the rectified current i_{rec} is fairly distorted from the absolute value of the sinusoidal wave.

[0161] On the contrary, with the method in this embodiment, even when the virtual DC link voltage V_{dc} is made to be larger than $1/\sqrt{2}$ times the crest value of the rectified voltage V_{rec} , the rectified current i_{rec} can show the sinusoidal waveform.

[0162] Fig. 14 and Fig. 15 are graphs showing waveforms of specifications in a case where the control is made by simulation according to the method in this embodiment (“example 3”). Waveforms of specifications corresponding to Fig. 10 and Fig. 11 are respectively shown. It is noted that a case is shown where the crest value of the rectified

voltage V_{rec} is set to 300 V similarly to Fig. 10 to Fig. 11, the virtual DC link voltage V_{dc} is set to 0.8 (240 V) times the crest value of the rectified voltage V_{rec} , and further the waveform of the rectified current i_{rec} is the absolute value of the sinusoidal wave.

[0163] The peak value of the electric current i_b comes to 15.0 A and is still smaller
 5 than the comparative example 2. Furthermore, since the waveform of the rectified current i_{rec} is the absolute value of the sinusoidal wave, generation of so-called power line harmonics can be suppressed. Such an effect of the example 3 cannot be realized as long as the condition (i) is maintained even if the condition (ii) is removed.

[0164] Fig. 16 and Fig. 17 are graphs showing waveforms of specifications in a case
 10 where the control is made by simulation according to the method in this embodiment ("example 4"). Waveforms of specifications corresponding to Fig. 10 and Fig. 11 are respectively shown. It is noted that a case is shown where the crest value of the rectified voltage V_{rec} is set to 300 V similarly to Fig. 10 to Fig. 11, the virtual DC link voltage V_{dc} is made to be equal to the crest value of the rectified voltage V_{rec} , and further the
 15 waveform of the rectified current i_{rec} is the absolute value of the sinusoidal wave.

[0165] When the virtual DC link voltage V_{dc} is equal to the crest value of the rectified voltage V_{rec} as that, $dc = 0$ holds only at a time of 90° or 270° . Therefore, Fig. 16 and Fig. 17 do not show the "charge" period.

[0166] Further, when the virtual DC link voltage V_{dc} is smaller than the capacitor
 20 voltage V_c , control for making the rectified voltage V_{rec} always large is enabled. In this case, $dc > 0$ always holds, and there is no case where step S106 is executed as shown in the flowchart of Fig. 5. Surely, since the formula (1) holds, $dr < 1$.

[0167] As is understood from the comparison between the examples 1 and 2 and the comparative examples 1 and 2, the control using the method in this embodiment enables
 25 the peak value of the electric current i_b to flow in the direct AC power converter to be

reduced. This contributes to reductions of the loss in the boost chopper 3, and a rated current of the inductor 32.

[0168] It is understood from the examples 2, 3, and 4 that the virtual DC link voltage V_{dc} can be set to $1/\sqrt{2}$ or more times the crest value of the rectified voltage V_{rec} .

5 [0169] As understood particularly from the comparison between the examples 2 and 3 and the comparative examples 2 and 3, the waveform of the rectified current i_{rec} can be the absolute value of the sinusoidal wave. This contributes to the suppression of the power line harmonics.

[0170] In the case where the electric power to be discharged from the capacitor 34 in
10 the “discharge” zone can be fed by the charge of the capacitor in the “charge/discharge” zone, when the virtual DC link voltage V_{dc} is smaller than the rectified voltage V_{rec} , the charge of the capacitor 34 may be unnecessary.

[0171] The present invention is described in detail, but the above description is the example from all aspects, and thus the invention is not limited to it. It is understood that
15 a lot of modified examples that are not illustrated here can be assumed without departing from the scope of the present invention.

CLAIMS

1. A direct AC power converter comprising:

a DC link (7) having a first power supply line (L1) and a second power supply
5 line (L2), an electric potential lower than an electric potential of said first power supply
line being applied to said second power supply line;

a first rectifying circuit (5, 51) having a plurality of input terminals that input an
AC voltage and a pair of output terminals (51c, 51d), each of which is connected to said
DC link;

10 an inverter (6) that converts a voltage applied to said DC link into another AC
voltage;

a boost chopper (3) having a capacitor (34) at an output stage; and

a switch (41) that performs discharge/non-discharge from said capacitor to said
DC link,

15 wherein in said boost chopper, charge into said capacitor is performed at least at
a first period being a part of a period during which a discharge duty (dc) as a time ratio of
continuity of said switch is larger than 0.

2. The direct AC power converter according to claim 1, wherein said capacitor
(34) is charged in said boost chopper at said first period and a part or an entire of the
20 period during which said discharge duty (dc) is 0.

3. The direct AC power converter according to claim 2, wherein

said capacitor (34) is charged/discharged by a charge power (Pci) and a
discharge power (Pco) at said first period, and

said first period has a period during which said charge power is larger than said
25 discharge power, and a period during which said discharge power is larger than said

charge power.

4. The direct AC power converter according to claim 2, wherein

a virtual DC link voltage (V_{dc}) represented by a sum of a product ($dc \cdot V_c$) of said discharge duty (dc) and a voltage between both ends (V_c) of said capacitor (34) and a product ($dr \cdot V_{rec}$) of a rectifying duty (dr) and a rectified voltage (V_{rec}) of said AC voltage is larger than $1/\sqrt{2}$ times said rectified voltage,

said rectifying duty takes a value obtained by subtracting a sum of said discharge duty and a zero voltage duty (dz) from 1,

said zero voltage duty is a time ratio for said inverter (6) to take on a zero voltage vector regardless a magnitude of a voltage output from said inverter (6).

5. The direct AC power converter according to claim 3, wherein

a virtual DC link voltage (V_{dc}) represented by a sum of a product ($dc \cdot V_c$) of said discharge duty (dc) and a voltage between both ends (V_c) of said capacitor (34) and a product ($dr \cdot V_{rec}$) of a rectifying duty (dr) and a rectified voltage (V_{rec}) of said AC voltage is larger than $1/\sqrt{2}$ times said rectified voltage,

said rectifying duty takes a value obtained by subtracting a sum of said discharge duty and a zero voltage duty (dz) from 1,

said zero voltage duty is a time ratio for said inverter (6) to take a zero voltage vector regardless a magnitude of a voltage output from said inverter (6).

20 6. The direct AC power converter according to claim 2, wherein

said discharge duty that makes said zero voltage duty (dz) minimum is set based on a command value (i_{rec}^*) of a rectified current (i_{rec}) being a sum of an electric current (i_b) flowing in said boost chopper (3) and an electric current (i_{direct}) flowing from said first rectifying circuit to said inverter (6), a command value (V_{dc}^*) of said virtual DC link voltage (V_{dc}), the voltage between both ends (V_c) of said capacitor, said rectified voltage

(Vrec), and an electric current (idc) to be input into said inverter (6).

7. The direct AC power converter according to claim 3, wherein

said discharge duty that makes said zero voltage duty (dz) minimum is set based on a command value (irec*) of a rectified current (irec) being a sum of an electric current (ib) flowing in said boost chopper (3) and an electric current (idirect) flowing from said first rectifying circuit to said inverter (6), a command value (Vdc*) of said virtual DC link voltage (Vdc), the voltage between both ends (Vc) of said capacitor, said rectified voltage (Vrec), and an electric current (idc) to be input into said inverter (6).

8. The direct AC power converter according to claim 4, wherein

said discharge duty that makes said zero voltage duty (dz) minimum is set based on a command value (irec*) of a rectified current (irec) being a sum of an electric current (ib) flowing in said boost chopper (3) and an electric current (idirect) flowing from said first rectifying circuit to said inverter (6), a command value (Vdc*) of said virtual DC link voltage (Vdc), the voltage between both ends (Vc) of said capacitor, said rectified voltage (Vrec), and an electric current (idc) to be input into said inverter (6).

9. The direct AC power converter according to claim 6, wherein

when said virtual DC link voltage (Vdc) is larger than said rectified voltage (Vrec) and said command value (irec*) of said rectified current (irec) is a predetermined value (dr_max) or more, said rectifying duty (dr) takes said predetermined value, and said discharge duty (dc) takes a value obtained by subtracting said predetermined value from 1,

said predetermined value is a value $((Vdc^* - Vc) / (Vrec - Vc))$ obtained by dividing a value obtained by subtracting said voltage between both ends (Vc) of said capacitor from said command value (Vdc*) of a virtual DC link voltage (Vdc) by a value obtained by subtracting said voltage between both ends (Vc) from said rectified voltage

(Vrec).

10. The direct AC power converter according to claim 7, wherein

when said virtual DC link voltage (Vdc) is larger than said rectified voltage (Vrec) and said command value (irec*) of said rectified current (irec) is a predetermined value (dr_max) or more, said rectifying duty (dr) takes said predetermined value, and said discharge duty (dc) takes a value obtained by subtracting said predetermined value from 1, and

said predetermined value is a value $((Vdc^* - Vc) / (Vrec - Vc))$ obtained by dividing a value obtained by subtracting said voltage between both ends (Vc) of said capacitor from said command value (Vdc*) of a virtual DC link voltage (Vdc) by a value obtained by subtracting said voltage between both ends (Vc) from said rectified voltage (Vrec).

11. The direct AC power converter according to claim 8, wherein

when said virtual DC link voltage (Vdc) is larger than said rectified voltage (Vrec) and said command value (irec*) of said rectified current (irec) is a predetermined value (dr_max) or more, said rectifying duty (dr) takes said predetermined value, and said discharge duty (dc) takes a value obtained by subtracting said predetermined value from 1, and

said predetermined value is a value $((Vdc^* - Vc) / (Vrec - Vc))$ obtained by dividing a value obtained by subtracting said voltage between both ends (Vc) of said capacitor from the command value (Vdc*) of a virtual DC link voltage (Vdc) by a value obtained by subtracting said voltage between both ends (Vc) from said rectified voltage (Vrec).

12. The direct AC power converter according to claim 1, further comprising a second rectifying circuit (52) for inputting said rectified voltage (Vrec) into said boost

chopper (3).

13. The direct AC power converter according to claim 2, further comprising a second rectifying circuit (52) for inputting said rectified voltage (V_{rec}) into said boost chopper (3).

5 14. The direct AC power converter according to claim 1, wherein said pair of output terminals of said first rectifying circuit is connected to an input side of said boost chopper.

15. The direct AC power converter according to claim 2, wherein said pair of output terminals of said first rectifying circuit is connected to an input side of said boost
10 chopper.

16. The direct AC power converter according to claim 1, wherein said discharge duty (dc) is always positive.

17. The direct AC power converter according to claim 2, wherein said discharge duty (dc) is always positive.

15 18. The direct AC power converter according to claim 1, further comprising:
a diode parallel with said switch (41), said diode making a direction of charging said capacitor (34) from said DC link (7) being a forward direction.

19. The direct AC power converter according to claim 2, further comprising:
a diode parallel with said switch (41), said diode making a direction of charging
20 said capacitor (34) from said DC link (7) being a forward direction.