(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
27 August 2015 (27.08.2015)

(10) International Publication Number
WO 2015/125591 A2

(51) International Patent Classification:
H02P 27/08 (2006.01)

(21) International Application Number:
PCT/JP2015/052782

(22) International Filing Date:
23 January 2015 (23.01.2015)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
2014-032290 21 February 2014 (21.02.2014) JP

(71) Applicant: **TOYOTA JIDOSHA KABUSHIKI KAISHA** [JP/JP]; 1, Toyota-cho, Toyota-shi, Aichi, 4718571 (JP).

(72) Inventor: **OI, Shohei**; c/o TOYOTA JIDOSHA KABUSHIKI KAISHA, 1, Toyota-cho, Toyota-shi, Aichi, 4718571 (JP).

(74) Agent: **YKI PATENT ATTORNEYS**; 1-34-12, Kichijoji-Honcho, Musashino-shi, Tokyo, 1800004 (JP).

(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

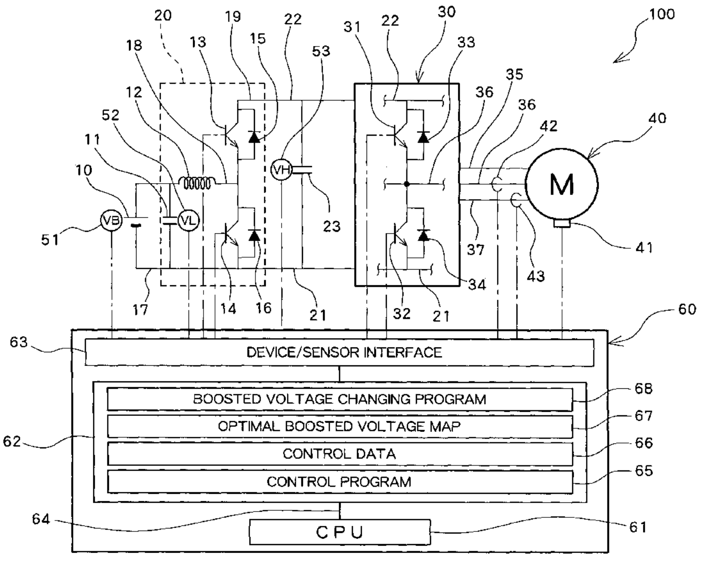
(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:

— *without international search report and to be republished upon receipt of that report (Rule 48.2(g))*

(54) Title: MOTOR CONTROL SYSTEM

FIG. 1



(57) Abstract: A motor control system (100) include an inverter (30) configured to convert boosted direct-current electric power output from a boost converter (20) to alternating-current electric power and supply the alternating-current electric power to an alternating current motor (40), and a control unit (60) configured to adjust boosted voltage of the boost converter (20). The control unit (60) includes an optimal boosted voltage map (67) which defines optimal boosted voltage for operating the alternating current motor (40) with a required number of revolutions and required torque, and a boosted voltage changing program (68) that sets boosted voltage (direct-current high voltage VH) of the boost converter (20) to a voltage which is higher than an optimal boosted voltage VHs when the carrier frequency Fc is a predetermined threshold value Fc_0 or lower.

WO 2015/125591 A2

DESCRIPTION

TITLE OF INVENTION

MOTOR CONTROL SYSTEM

TECHNICAL FIELD

The present invention relates to a motor control system designed to convert direct-current electric power, which is boosted, to alternating-current electric power for driving a motor.

BACKGROUND

Motor control systems designed to convert direct-current electric power supplied from a direct-current power source, such as a battery, to alternating-current electric power by an inverter for driving a motor, such as a three-phase synchronous electric machine, are in wide use. An inverter turns a plurality of switching elements on/off at a predetermined carrier frequency, thereby converting direct-current electric power to three-phase alternating-current electric power. When the carrier frequency is high and the on/off operations are performed with a high frequency, the waveform of the output three-phase alternating-current electric power is smooth, which makes control for the motor stabilized; however, the temperature of the switching elements increases due to a large amount of heat generated by the switching elements. On the other hand, when the carrier frequency is low and the on/off operations are performed with a low frequency, the waveform of the output three-phase alternating-current electric power includes fluctuation components, which deteriorate stability of motor control; however, the temperature rise in the switching elements is reduced, as the amount of heat generated by the switching elements is not so great. Therefore, in general, high carrier frequencies are used when the number of revolutions of a motor is high, whereas low carrier frequencies are used when the number of revolutions of a motor is low. Further, when the output torque of a motor is large, the amount of heat generated by the switching elements is large, as a great amount of electric current flows therein, whereas when the output torque of a motor is small, the amount of heat generated by the switching elements is also small, as a small amount of electric current flows therein. Accordingly, there is proposed a control method for controlling the carrier frequency to a low level when the motor has a low number of revolutions and a large torque, in order to suppress heat generation and temperature rise of the switching elements, and controlling the carrier frequency to a high level when the motor has a high number of revolutions, in order to ensure stability of control (see Patent Document 1, for example).

PRIOR ART DOCUMENTS

PATENT LITERATURE

Patent Document 1: JP 2002-010668 A

SUMMARY OF INVENTION

TECHNICAL PROBLEM

However, the operation of an inverter at a low carrier frequency when the motor has a low number of revolutions and a large torque would result in driving the motor with a large alternating current containing fluctuation components, which increases fluctuation of the torque of the motor, causing significant variations in a counterelectromotive force from the motor. This may induce fluctuations of voltage of the inverter.

On the other hand, in order to operate the motor with the number of revolutions and torque in a wider range, recently, there has widely been used a method for boosting the voltage of the battery by a boost converter and converting the boosted direct-current electric power to alternating-current electric power by an inverter, thereby driving a motor. If the inverter is operated at a low carrier frequency to drive the motor with a low number of revolutions and great torque in a motor control apparatus which performs such boosting, fluctuations in the counterelectromotive force of the motor increase, to thereby significantly fluctuate the boosted voltage, which may lead to degradation in the control performance of the boost converter.

The present invention is aimed at suppressing fluctuations of the boosted voltage in a motor control system, when an inverter is driven at a low carrier frequency for operating a motor with a low number of revolutions and large torque.

SOLUTION TO PROBLEM

In accordance with an aspect of the invention, there is provided a motor control system including a boost converter configured to turn a plurality of first switching elements on/off at a predetermined carrier frequency to boost voltage of a battery and obtain boosted direct-current electric power, an inverter configured to turn a plurality of second switching elements on/off at a predetermined carrier frequency to convert the boosted direct-current electric power output from the boost converter to alternating-current electric power and supply the alternating-current electric power to a motor, and a control unit configured to adjust boosted voltage of the boost converter. The control unit includes an optimal boosted voltage map that defines optimal boosted voltage for operating the motor with a required number of revolutions and required torque, and boosted voltage changing means configured, when the carrier frequency is equal to or lower than a predetermined threshold value, to set the boosted voltage of the boost converter to a voltage which is higher than the optimal boosted voltage defined by the optimal boosted voltage map.

Preferably, in the motor control system according to the present invention, the boosted voltage changing means sets the boosted voltage of the boost converter to a system maximum voltage when the carrier frequency is equal to or lower than the predetermined threshold value.

Preferably, in the motor control system according to the present invention, the boosted voltage changing means sets the boosted voltage of the boost converter to a higher voltage as the torque of the motor is larger, when the carrier frequency is equal to or lower than the predetermined threshold value.

In accordance with another aspect of the invention, there is provided a motor control system including a boost converter configured to turn a plurality of first switching elements on/off at a predetermined carrier frequency to boost voltage of a battery and obtain boosted direct-current electric power, an inverter configured to turn a plurality of second switching elements on/off at a predetermined carrier frequency to convert the boosted direct-current electric power output from the boost converter to alternating-current electric power, the inverter supplying the alternating-current electric power to a motor, and a control unit including a CPU and configured to adjust boosted voltage of the boost converter. The control unit includes an optimal boosted voltage map that defines optimal boosted voltage for operating the motor with a required number of revolutions and required torque, and causes the CPU to execute a boosted voltage changing program for setting, when the carrier frequency is equal to or lower than a predetermined threshold value, the boosted voltage of the boost converter to a voltage which is higher than the optimal boosted voltage defined by the optimal boosted voltage map.

ADVANTAGEOUS EFFECTS OF INVENTION

The present invention can achieve an advantage that fluctuations of the boosted voltage can be suppressed in a motor control system, when the inverter is driven at a low carrier frequency to operate the motor with a low number of revolutions and large torque.

BRIEF DESCRIPTION OF DRAWINGS

Preferred embodiments of the present invention will be described in detail by reference to the following figures, wherein:

FIG. 1 is a system diagram illustrating a structure of a motor control system according to an embodiment of the present invention;

FIG. 2A is a map of the optimal boosted voltage with respect to the number of revolutions stored in a control unit of the motor control system according to the embodiment of the present invention;

FIG. 2B is a map of the carrier frequency with respect to the number of revolutions stored in the control unit of the motor control system according to the embodiment of the present invention; and

FIG. 3 is a graph showing the boosted voltage (direct-current high voltage VH) with respect to the motor torque of the motor control system according to the embodiment of the present invention.

DESCRIPTION OF EMBODIMENTS

Preferred embodiments of the present invention will be described in detail with reference to the accompanying drawings. As illustrated in FIG.1, the motor control system according to the present embodiment includes a battery 10, which is a chargeable secondary battery, a boost converter 20 connected to the battery 10, an inverter 30 connected to the boost converter 20, an alternating current motor 40 connected to the inverter 30, and a control unit 60 for controlling the boost converter 20 and the inverter 30. A battery voltage sensor 51 that detects battery voltage VB is mounted to the battery 10, and a resolver 41 that detects the number of revolutions and the rotation angle is mounted to the alternating current motor 40.

As illustrated in FIG. 1, the boost converter 20 includes a negative side electric path 17 connected to a negative side of the battery 10, a low voltage electric path 18 connected to a positive side of the battery 10, and a high voltage electric path 19 at a positive side output terminal of the boost converter 20. The boost converter 20 includes an upper arm switching element (first switching element) 13 disposed between the low voltage electric path 18 and the high voltage electric path 19, a lower arm switching element (first switching element) 14 disposed between the negative side electric path 17 and the low voltage electric path 18, a reactor 12 disposed in series with the low voltage electric path 18, a filter capacitor 11 disposed between the low voltage electric path 18 and the negative side electric path 17, and a low voltage sensor 52 that detects direct-current low voltage VL across the filter capacitor 11. Each of the switching elements 13 and 14 includes a diode 15, 16 connected antiparallel thereto. The boost converter 20, after turning the lower arm switching element 14 on and turning the upper arm switching element 13 off at a predetermined carrier frequency Fc to store the electric energy from the battery 10 in the reactor 12, turns the lower arm switching element 14 off and turns the upper arm switching element 13 on, to boost the voltage by the electric energy stored in the reactor 12 and supplies direct-current high voltage VH, which is boosted voltage, to the high voltage electric path 19. The on/off time ratio of the upper arm switching element 13 and the on/off time ratio of the lower arm switching element 14 are determined according to a ratio between the direct-current low voltage VL and the direct-current high voltage VH.

The inverter 30 includes a common high voltage electric path 22 connected to the high voltage electric path 19 of the boost converter 20, and a common negative side electric path 21 connected to the negative side electric path 17 of the boost converter 20. A smoothing capacitor 23 is connected between the high voltage electric path 22 and the negative side electric path 21 in order to smooth the direct current supplied from the boost converter 20. The direct-current high voltage VH, which is boosted voltage supplied to the inverter 30 is detected by a high voltage sensor 53 that detects the voltage at both ends of the smoothing capacitor 23. Accordingly, the direct-current high voltage VH detected by the high voltage sensor 53 is actual boosted voltage (actual boosted voltage VHr). The inverter 30 converts the direct-current electric power supplied from the boost converter 20 to three-phase alternating-current electric power, which is then supplied to the alternating current motor 40.

The inverter 30 includes therein a total of six switching elements, including an upper arm switching element 31 and a lower arm switching element 32, which are second switching elements, for each of U, V, and W phases. A diode 33, 34 is connected antiparallel with each switching element 31, 32. (Note that FIG. 1 illustrates only upper and lower switching elements 31 and 32 for one phase and associated diodes 33 and 34, and does not illustrate switching elements and didoes for other phases). In the inverter 30, between the upper arm switching element and the lower arm switching element for each of U, V, and W phases, an output line 35, 36, 37 for outputting electric current of each of U, V, and W phases is mounted, and each output line 35, 36, 37 is connected to an input terminal for each of U, V, and W phases of the alternating current motor 40. According to the present embodiment, current sensors 42 and 43 are provided to the output lines 36 and 37 for V phase and W phase, respectively, for detecting the respective electric currents. While the current sensor is not provided to the output line 35 of U phase, the electric current value of U phase can be obtained by calculation of the electric current values of V phase and W phase, because a sum of the electric currents of U, V, and W phases is zero in three-phase alternating current.

As illustrated in FIG. 1, the control unit 60 is a computer including a CPU 61 that performs operation processing, a storage unit 62, and a device/sensor interface 63, and the CPU 61 that performs operation processing is connected to the storage unit 62 and the device/sensor interface 63 via a data bus 64. The storage unit 62 stores therein a control program 65 and control data 66 for the alternating current motor, and an optimal boosted voltage map 67 and a boosted voltage changing program 68 which will be described below. Each of the switching elements 13 and 14 of the boost converter 20 and the switching elements 31 and 32 of the inverter 30, which have been described above, is connected to the control unit 60 through the device/sensor interface 63 and is configured to operate under command from the control unit 60. Further, each sensor output from the battery voltage sensor 51, the low voltage sensor 52, the high voltage sensor 53, and the resolver 41 is input to the control unit 60 through the device/sensor interface 63.

By reference to to FIG. 2A, the optimal boosted voltage map 67 stored in the storage unit 62 will be described. The optimal boosted voltage map 67 illustrated in FIG. 2A shows, in a map, the optimal values of the direct-current high voltage VH (optimal boosted voltage VHs) supplied to the inverter 30 by the boost converter 20 for operating the alternating current motor 40 with a requested number of revolutions and requested torque. In FIG. 2A, a solid line (a) shows the optimal boosted voltage VHs in a case where the alternating current motor 40 has large torque T ($T = T_1$); a dashed and single-dotted line (b) shows the optimal boosted voltage VHs in a case where the alternating current motor 40 has intermediate torque T ($T = T_2 < T_1$); and a dashed line (c) shows the optimal boosted voltage VHs in a case where the alternating current motor 40 has small torque T ($T = T_3 < T_2 < T_1$).

As shown by the solid line (a) in FIG. 2A, in a case where the torque T of the alternating current motor 40 is T_1 (when the torque T is large), when the number of revolutions R of the alternating current motor 40 is between 0 and N_1, the optimal boosted voltage VHs is VHs_1, which is about 75% of the system maximum voltage VHmax. Here, the system maximum voltage VHmax is the maximum voltage that can be continuously applied to each of the alternating current motor 40, the boost converter 20, and the inverter 30. When the number of revolutions R of the alternating current motor 40 exceeds N_1, the optimal boosted voltage VHs drops from VHs_1 to a voltage which is slightly higher than the system minimum voltage VHs_0 (e.g, battery voltage VB) that is the minimum voltage which can be continuously applied to each of the alternating current motor 40, the boost converter 20, and the inverter 30. When the number of revolutions R of the alternating current motor 40 exceeds N_2 and continues to increase, the optimal boosted voltage VHs increases with the increase of the number of revolutions R, and reaches the system maximum voltage VHmax when the number of revolutions R of the alternating current motor 40 is N_6, and remains at the system maximum voltage VHmax when number of revolutions R of the alternating current motor 40 is N_6 or greater.

Further, as shown by the dashed and single-dotted line (b) in FIG. 2A, in the case where the torque T of the alternating current motor 40 is T_2 (when the torque T is intermediate), as with the case of the large torque T described above, the optimal boosted voltage VHs is VHs_1, when the number of revolutions R of the alternating current motor 40 is 0 to N_1. When the number of revolutions R of the alternating current motor 40 exceeds N_1, the optimal boosted voltage VHs decreases from VHs_1 to a voltage which is slightly higher than the system minimum voltage VHs_0, and when the number of revolutions R of the alternating current motor 40 increases after exceeding N_2, the optimal boosted voltage VHs also increases. The optimal boosted voltage VHs then reaches the system maximum VHmax when the number of revolutions R of the alternating current motor 40 R is N_7, which is higher than N_6, and remains at VHmax when the number of revolutions R of the alternating current motor 40 is N_7 or greater.

In the case where the torque T of the alternating current motor 40 is T_1 (when the torque T is small) as shown by the dashed line (c) in FIG. 2A, when the number of revolutions R of the alternating current motor 40 is 0 to N_1, the optimal boosted voltage VHs is VHs_3 which is about 30% of the system maximum voltage VHmax ($VHs_3 < VHs_1$). When the number of revolutions R of the alternating current motor 40 exceeds N_1, the optimal boosted voltage VHs lowers from VHs_3 to a voltage slightly higher than the system minimum voltage VHs_0, and when the number of revolutions R of the alternating current motor 40 increases after exceeding N_2, the optimal boosted voltage VHs increases as the number of revolutions R increases and reaches the system maximum voltage VHmax when the number of revolutions R of the alternating current motor 40 is N_8, which is higher than N_6 and N_7. The optimal boosted voltage VHs remains the at system maximum voltage VHmax when the number of revolutions R of the alternating current motor 40 is N_8 or greater.

As described above, when the number of revolutions of the alternating current motor 40 is lower than N_1, the optimal boosted voltage VHs is as follows: when the torque T of the alternating current motor 40 is large or intermediate, the optimal boosted voltage VHs is VHs_1, which is about 75% of the system maximum voltage VHmax, and when the torque T of the alternating current motor 40 is small, the optimal boosted voltage VHs is VHs_3, which is about 30% of the system maximum voltage VHmax. When the number of revolutions of the alternating current motor 40 is between N_1 and N_2, the optimal boosted voltage VHs is slightly higher than the system minimum voltage VHs_0. When the number of revolutions of the alternating current motor 40 exceeds N_2, the optimal boosted voltage VHs increases with an increasing ratio in accordance with the torque T as the number of revolutions R increases. Then, the optimal boosted voltage VHs reaches the system maximum voltage VHmax with the number of revolutions R of N_6 or greater when the torque T of the alternating current motor 40 is large; the optimal boosted voltage VHs reaches the system maximum voltage VHmax with the number of revolutions R of N_7, which is greater than N_6, or greater, when the torque T is intermediate; and the optimal boosted voltage VHs reaches the system maximum voltage VHmax with the number of revolutions R of N_8, which is greater than N_6 and N_7, or greater when the torque T is small.

The control unit 60 stores, in the control data 66 in the storage unit 62, a carrier frequency map that defines the carrier frequency Fc with respect to the number of revolutions R of the alternating current motor 40, as shown in FIG. 2B. As shown in FIG. 2B, the carrier frequency Fc is defined such that it increases in four steps as the number of revolutions R increases: the carrier frequency Fc is the lowest, at Fc_1, when the number of revolutions R of the alternating current motor 40 is between 0 and N_1; the carrier frequency Fc is rather high, at Fc_2, when the number of revolutions R is between N_1 and N_3; the carrier frequency Fc is a further little higher, at Fc_3, when the number of revolutions R is between N_3 and N_4; and the carrier frequency Fc is the highest, at Fc_4, when the number of revolutions R is N_4 or greater

Accordingly, as shown in FIG. 2A, with the number of revolutions R of the alternating current motor 40 of N_{11} and N_{12}, between 0 and N_1, when the torque T of the alternating current motor 40 is intermediate or greater, the boost converter 20 operates at operating points P_{11}, P_{12}, P_{21}, and P_{22} such that the boosted voltage (direct-current high voltage VH) is VHs_1 when the carrier frequency Fc is the lowest, at Fc_1, and when the torque T of the alternating current motor 40 is small, the boost converter 20 operates at operating points P_{13} and P_{23} such that the boosted voltage (direct-current high voltage VH) is VHs_3 which is about 30% of the system maximum voltage VHmax, when the carrier frequency Fc is the lowest, at Fc_1.

When the carrier frequency Fc is equal to or less than the predetermined threshold, the boosted voltage changing program 68 (boosted voltage changing means) of the motor control system 100 according to the present embodiment adjusts the boosted voltage (direct-current high voltage VH) of the boost converter 20 to a voltage which is higher than the optimal boosted voltage VHs defined by the optimal boosted voltage map 67.

Specifically, as shown in FIG. 2B, upon execution of the boosted voltage changing program 68, when the number of revolutions R of the alternating current motor 40 is N_{11}, and the carrier frequency Fc is Fc_1, which is lower than the predetermined threshold value Fc_0, the control unit 60 sets the boosted voltage (direct-current high voltage VH) of the boost converter 20 to the system maximum voltage VHmax, which is greater than the optimal boosted voltage VHs. Consequently, as shown in FIG. 2A, the operating points of the boost converter 20 are shifted from the operating points P_{11}, P_{12}, and P_{13} obtained before execution of the boosted voltage changing program 68 to P_{10}, so that the boost converter 20 supplies the boosted voltage, which is the system maximum voltage VHmax, to the inverter 30.

The electric energy Pc stored in the smoothing capacitor 23 having direct-current high voltage VH (boosted voltage) applied to the respective ends is represented by the following Formula 1, wherein C is a capacitance of the smoothing capacitor 23:

$$Pc = (1/2) \times C \times VH^2 \qquad \text{(Formula 1)}$$

Here, the energy ΔPc_1 required for a change of the direct-current high voltage VH by an amount of ΔVH when the direct-current high voltage VH is VHs_1 and the energy $\Delta Pcmax$ required for a change of the direct-current high voltage VH by an amount of ΔVH when the direct-current high voltage VH is VHmax are represented by the following formulas (Formula 2) and (Formula 3), respectively:

$$\Delta Pc_1 = (1/2) \times C \times [(VHs_1 + \Delta VH)^2 - VHs_1^2]$$
$$= (1/2) \times C \times [\Delta VH^2 + (2 \times VHs_1 \times \Delta VH)] \text{ -- (Formula 2)}$$

$$\Delta Pcmax = (1/2) \times C \times [(VHmax + \Delta VH)^2 - VHmax^2]$$
$$= (1/2) \times C \times [\Delta VH^2 + (2 \times VHmax \times \Delta VH)] \text{ -- (Formula 3)}$$

The difference between $\Delta Pcmax$ and ΔPc_1 is as follows:

$$\Delta Pcmax - \Delta Pc_1 = (1/2) \times C \times 2 \times \Delta VH \times (VHmax - VHs_1)$$
$$= C \times \Delta VH \times (VHmax - VHs_1) \quad \text{----- (Formula 4)}$$

As described above, as VHs_1 is about 75% of VHmax, and VHmax is larger than VHs_1 ($VHmax > VHs_1$), ($\Delta Pcmax - \Delta Pc_1$) in Formula 4 is positive, and $\Delta Pcmax$ is larger than ΔPc_1. Accordingly, a greater energy is required for changing the direct-current high voltage VH by an amount ΔVH when the direct-current high voltage VH is high than when the direct-current high voltage VH is low. In other words, when the direct-current high voltage VH is high, it is necessary to input greater energy than when the direct-current high voltage VH low in order to change the voltage by an amount of ΔVH. When the energy of the same level is input, a fluctuation width of the voltage is smaller when the direct-current high voltage VH is high than when the direct-current high voltage VH is low.

Accordingly, when the operating points of the boost converter 20 are shifted from the operating points P_{11}, P_{12}, and P_{13} obtained before execution of the boosted voltage changing program 68 to the operating point P_{10} obtained at the time of execution of the boosted voltage changing program 68, and the direct-current high voltage increases from VHs_1 or VHs_3 to VHmax as shown in FIG. 2A, the voltage fluctuation of the direct-current high voltage VH becomes smaller.

As described above, by using the boosted voltage changing program 68 to increase the boosted voltage to the system maximum voltage VHmax, even when the inverter 30 is driven with the carrier frequency Fc, which is lower than the predetermined threshold value Fc_0, so that the alternating current motor 40 is driven with alternating current containing a large amount of fluctuation components and therefore the torque fluctuations of the alternating current motor 40 and the fluctuations of the counterelectromotive force of the alternating current motor 40 are large, it is possible to suppress the voltage fluctuations of the direct-current high voltage VH supplied from the boost converter 20 to the inverter 30, thereby preventing deterioration of controllability of the boost converter 20. The suppression of fluctuations of VH can also prevent deterioration of control responsiveness of the alternating current motor 40.

While in the above example, the optimal boosted voltage map shows in a map the optimal value of the direct-current high voltage VH (optimal boosted voltage VHs) which is supplied from the boost converter 20 to the inverter 30 for operating the alternating current motor 40 with the required number of revolutions and the required torque, as shown in FIG. 2A, the optimal boosted voltage map is not limited to this example and may be maps of various forms. Another example optimal boosted voltage map is a required lower limit voltage map which defines the lower limit voltage for operating the alternating current motor 40 with the required number of revolutions and the required torque and shows the voltage which allows operation of the alternating current motor 40 with the required number of revolutions and the required torque, while minimizing (optimizing) the boost loss of the boost converter 20. In this case, according to the boosted voltage changing program 68, when the carrier frequency Fc is lower than the predetermined threshold value Fc_0, the boosted voltage may be increased to the lower limit voltage defined in the required lower limit voltage map or greater; e.g., to the system maximum voltage VHmax.

Another operation of the motor control system 100 according to the present embodiment will be described. In the above description concerning the operation with reference to FIG. 2A, when the torque of the alternating current motor 40 is between T_2 and T_1 and the number of revolutions R of the alternating current motor 40 is between 0 and N_1, the optimal boosted voltage VHs is set to VHs_1 according to the optimal boosted voltage map 67. Further, when the carrier frequency Fc is lower than the predetermined threshold value Fc_0, the boosted voltage (direct-current high voltage VH) is increased to the system maximum voltage VHmax according to the boosted voltage changing program 68. However, the boosted voltage (direct-current high voltage VH) may be increased to a voltage lower than the system maximum voltage VHmax, so long as the voltage fluctuations of the direct-current high voltage VH can be suppressed.

For example, as the torque T of the alternating current motor 40 is larger, a larger amount of electric current flows in the alternating current motor 40. Therefore, when the torque fluctuations occur in the alternating current motor 40, a counterelectromotive force with larger fluctuations is generated and large fluctuation energy is input to the smoothing capacitor 23. When the torque T is small, as a small amount of electric current flows in the alternating current motor 40, the counterelectromotive force generated at the time of the torque fluctuations is not very large. Accordingly, when the torque T of the alternating current motor 40 is small, even if the boosted voltage (direct-current high voltage VH) is set to a voltage lower than VHmax, it is possible to suppress the voltage fluctuations of the boosted voltage (direct-current high voltage VH).

The boosted voltage changing program 68 stores therein a map of the boosted voltage (direct-current high voltage VH) with respect to the torque T of the alternating current motor 40 as shown in FIG. 3. As shown by the solid line (d) in FIG. 3, when the torque T of the alternating current motor 40 is T_2, which is intermediate, the boosted voltage (direct-current high voltage VH) is VHs_1, similar to the case of the optimal boosted voltage map shown in FIG. 2A, and when the torque T is between T_2 and T_1 ($T_2 < T_1$), the boosted voltage (direct-current high voltage VH) increases as the torque T increases and reaches the system maximum voltage VHmax when the torque T exceeds T_1.

When the map shown in FIG. 3 is used, when the number of revolutions R of the alternating current motor 40 is N_{12} and the carrier frequency Fc is Fc_1 which is lower than the predetermined threshold value Fc_0 as shown in FIG. 2B, and when the torque of the alternating current motor 40 is T_3 which is between T_2 and T_1, the control unit 60 sets the boosted voltage (direct-current high voltage VH) to VHs_5 which is higher than VHs_1 and lower than VHmax. With this setting, the operating point of the boost converter 20 is shifted from the operating point P_{21} obtained prior to execution of the boosted voltage changing program 68 to the operating point P_{25} obtained by execution of the boosted voltage changing program 68, and the boost converter 20 supplies the boosted voltage (direct-current high voltage VH) of VHs_5 to the inverter 30. When the torque of the alternating current motor 40 is T_4, which is between T_2 and T_1 and larger than T_3, the control unit 60 sets the boosted voltage (direct-current high voltage VH) to VHs_4, which is higher than VHs_1 and VHs_5 and lower than VHmax. With this setting, the operating point of the boost converter 20 is shifted from the operating point P_{22} obtained prior to execution of the boosted voltage changing program 68 to the operating point P_{24} obtained by execution of the boosted voltage changing program 68, and the boost converter 20 supplies the boosted voltage (direct-current high voltage VH) of VHs_4 to the inverter 30. Similarly, when the torque T of the alternating current motor 40 is T_2, which is intermediate, the boost converter 20 supplies the boosted voltage (direct-current high voltage VH) of VHs_1 to the inverter 30, and when the torque T of the alternating current motor 40 exceeds T_1, the boost converter 20 supplies the boosted voltage (direct-current high voltage VH) of VHmax to the inverter 30.

With this operation, similar to the operation of the above described example, it is possible to suppress the fluctuations of the boosted voltage (direct-current high voltage VH) generated when the inverter 30 is driven with the low carrier frequency Fc and the alternating current motor 40 is driven with the low number of revolutions and large torque. Also, as the boosted voltage (direct-current high voltage VH) is not increased to VHmax but is increased only to a voltage lower than VHmax in accordance with the torque T of the alternating current motor 40, it is possible to suppress the fluctuations of the boosted voltage (direct-current high voltage VH) while suppressing the increase in the loss of the boost converter 20.

The map shown in FIG. 3 can include a plurality of lines. When the capacitance of the smoothing capacitor 23 is large, for example, as the fluctuations of the boosted voltage (direct-current high voltage VH) are small, the boosted voltage (direct-current high voltage VH) is maintained at VHs_1 until the torque T of the alternating current motor 40 reaches T_2', which is larger than T_2, and the boosted voltage (direct-current high voltage VH) is increased as the torque T increases with the torque T being between T_2' and T_1', which is larger than T_1, and then reaches the system maximum voltage VHmax with the torque T exceeding T_1', which is larger than T_1, as shown by the dashed line (e) in FIG. 3, so that the boosted voltage (direct-current high voltage VH) may be increased to a voltage which is lower than that in the case of the solid line (d) under the condition that the torque T is the same.

In the case of executing the boosted voltage changing program 68 with the use of the relationship indicated by the dashed line (e) in FIG. 3, the boosted voltage (direct-current high voltage VH) is lower than when executing the boosted voltage changing program 68 with the use of the relationship indicated by the solid line (d) in FIG. 3, when the torque T is the same. It is therefore possible to suppress the fluctuations of the boosted voltage (direct-current high voltage VH) more efficiently while suppressing the increase in the loss of the boost converter 20, as compared to the case of using the relationship shown by the solid line (d).

The present invention is not limited to each embodiment described above and may include all changes and corrections which do not depart from the technical scope or gist of the present invention defined by the appended claims.

REFERENCE SIGNS LIST

10 battery, 11 filter capacitor, 12 reactor, 13, 31 upper arm switching element, 14, 32 lower arm switching element, 15, 16, 33, 34 diode, 17, 21 negative side electric path, 18 low voltage electric path, 19, 22 high voltage electric path, 20 boost converter, 23 smoothing capacitor, 30 inverter, 35, 36, 37 output line, 40 alternating current motor, 41 resolver, 42, 43 current sensor, 51 battery voltage sensor, 52 low voltage sensor, 53 high voltage sensor, 60 control unit, 61 CPU, 62 storage unit, 63 device/sensor interface, 64 data bus, 65 control program, 66 control data, 67 optimal boosted voltage map, 68 boosted voltage changing program, 100 motor control system.

CLAIMS

1. A motor control system comprising:

a boost converter configured to turn a plurality of first switching elements on/off at a predetermined carrier frequency to boost voltage of a battery and obtain boosted direct-current electric power;

an inverter configured to turn a plurality of second switching elements on/off at a predetermined carrier frequency to convert the boosted direct-current electric power output from the boost converter to alternating-current electric power, the inverter supplying the alternating-current electric power to a motor; and

a control unit configured to adjust boosted voltage of the boost converter,

the control unit including:

an optimal boosted voltage map that defines optimal boosted voltage for operating the motor with a required number of revolutions and required torque; and

boosted voltage changing means configured, when the carrier frequency is equal to or lower than a predetermined threshold value, to set the boosted voltage of the boost converter to a voltage which is higher than the optimal boosted voltage defined by the optimal boosted voltage map.

2. The motor control system according to claim 1, wherein

the boosted voltage changing means sets the boosted voltage of the boost converter to a system maximum voltage when the carrier frequency is equal to or lower than the predetermined threshold value.

3. The motor control system according to claim 1, wherein

the boosted voltage changing means sets the boosted voltage of the boost converter to a higher voltage as the torque of the motor is larger, when the carrier frequency is equal to or lower than the predetermined threshold value.

4. A motor control system comprising:

a boost converter configured to turn a plurality of first switching elements on/off at a predetermined carrier frequency to boost voltage of a battery and obtain boosted direct-current electric power;

an inverter configured to turn a plurality of second switching elements on/off at a predetermined carrier frequency to convert the boosted direct-current electric power output from the boost converter to alternating-current electric power, the inverter supplying the alternating-current electric power to a motor; and

a control unit including a CPU and configured to adjust boosted voltage of the boost converter,

the control unit including an optimal boosted voltage map that defines optimal boosted voltage for operating the motor with a required number of revolutions and required torque, and

the control unit causing the CPU to execute a boosted voltage changing program for setting, when the carrier frequency is equal to or lower than a predetermined threshold value, the boosted voltage of the boost converter to a voltage which is higher than the optimal boosted voltage defined by the optimal boosted voltage map.

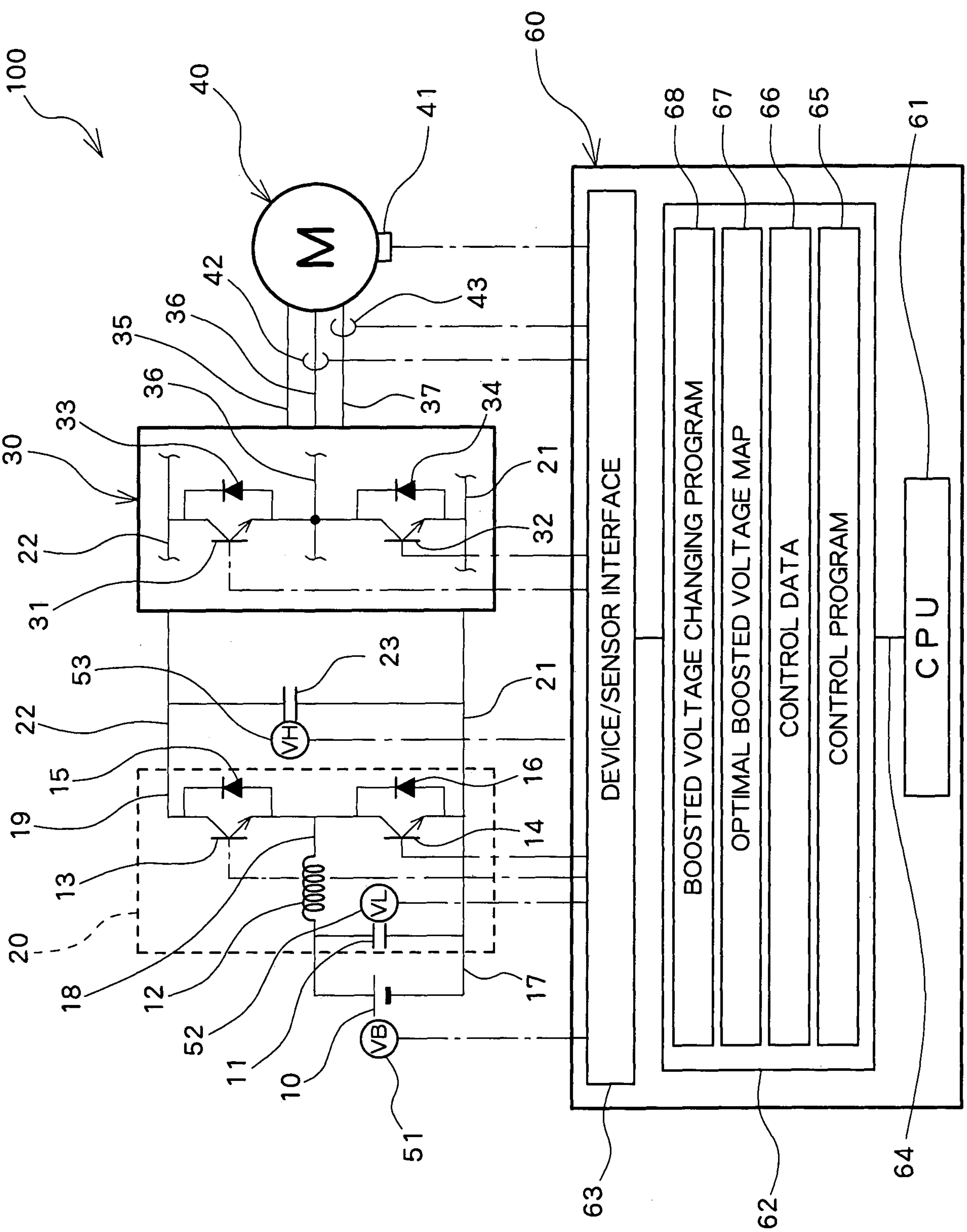

100
40
41
60
M
42
43
36
35
36
37
34
33
30
22
31
32
21
53
23
22
21
15
19
16
13
14
20
18
12
52
VH
VL
VB
11
10
17
51
DEVICE/SENSOR INTERFACE
BOOSTED VOLTAGE CHANGING PROGRAM
OPTIMAL BOOSTED VOLTAGE MAP
CONTROL DATA
CONTROL PROGRAM
CPU
68
67
66
65
61
63
62
64

FIG. 1

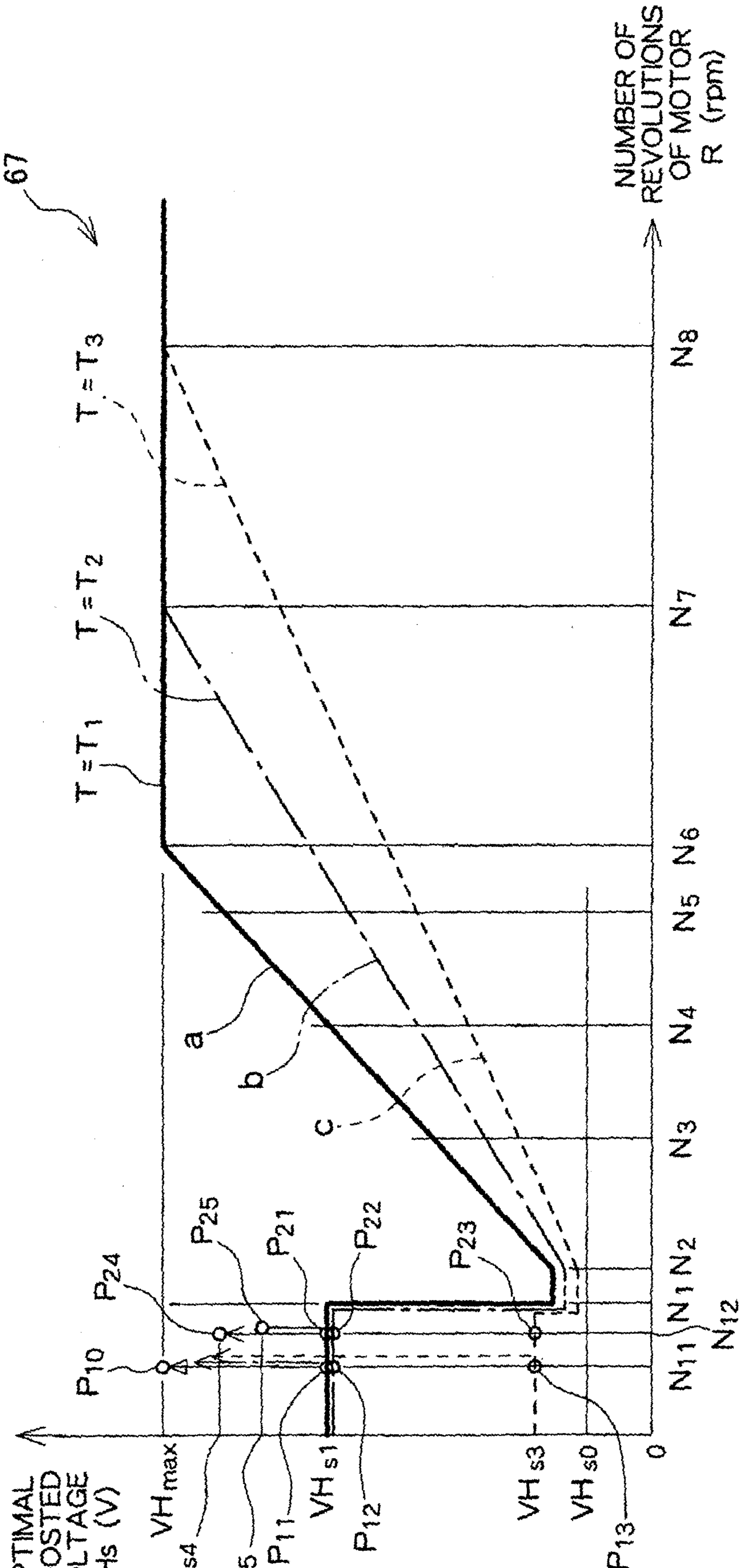

67
OPTIMAL BOOSTED VOLTAGE VHs (V)
VHmax
VHs4
VHs5
VHs1
VHs3
VHs0
0
P10
P11
P12
P13
P21
P22
P23
P24
P25
N11
N12
N1
N2
N3
N4
N5
N6
N7
N8
a
b
c
T = T1
T = T2
T = T3
NUMBER OF REVOLUTIONS OF MOTOR R (rpm)

FIG. 2A

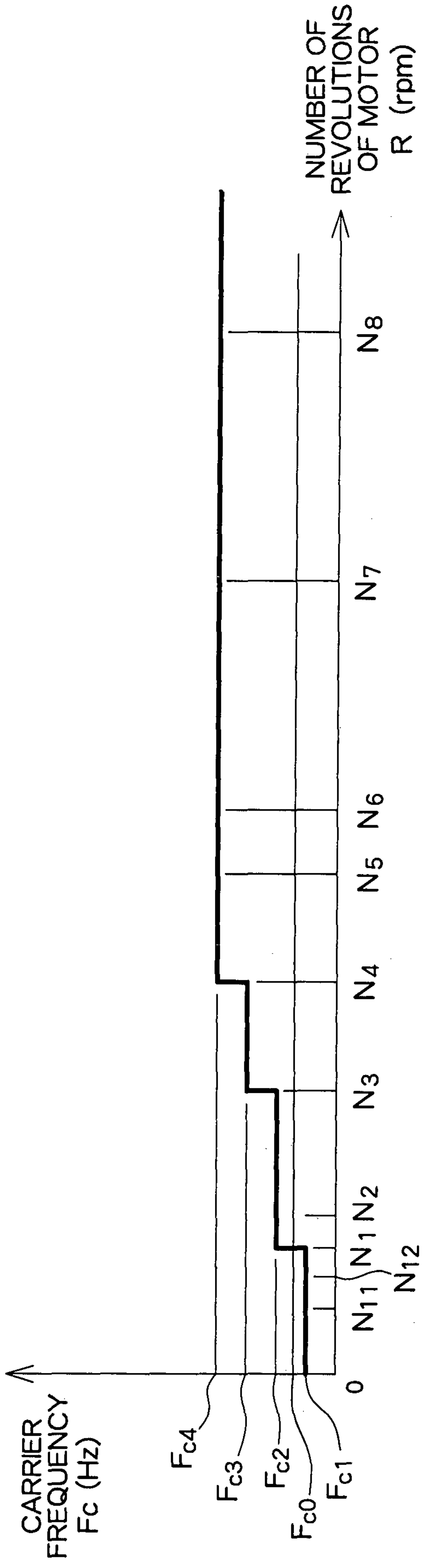

NUMBER OF REVOLUTIONS OF MOTOR R (rpm)
CARRIER FREQUENCY Fc (Hz)
F_{c4}
F_{c3}
F_{c2}
F_{c0}
F_{c1}
0
N_{11}
N_{12}
N_1
N_2
N_3
N_4
N_5
N_6
N_7
N_8

FIG. 2B

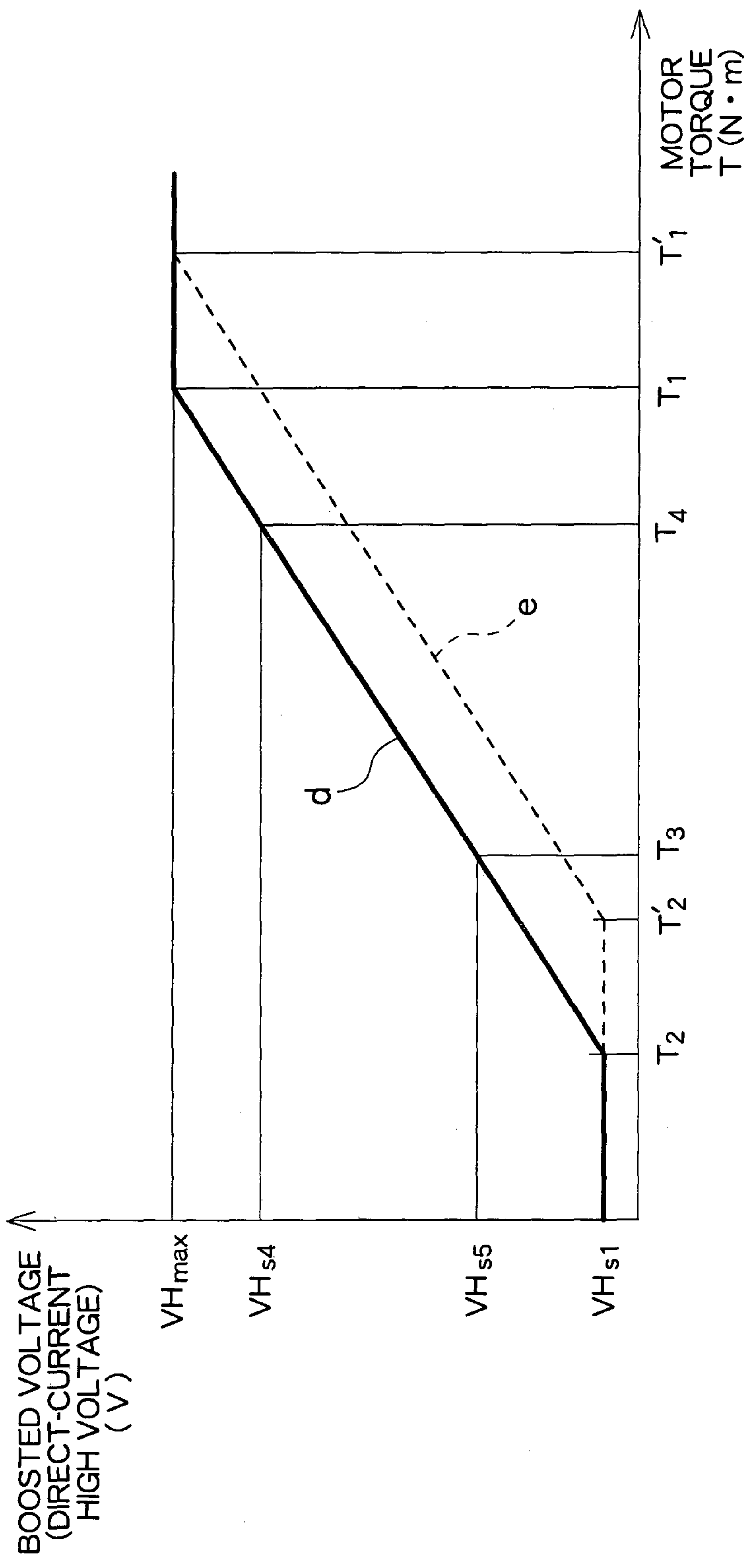

BOOSTED VOLTAGE (DIRECT-CURRENT HIGH VOLTAGE) (V)
VHmax
VHs4
VHs5
VHs1
MOTOR TORQUE T (N・m)
T2
T'2
T3
T4
T1
T'1
d
e

FIG. 3