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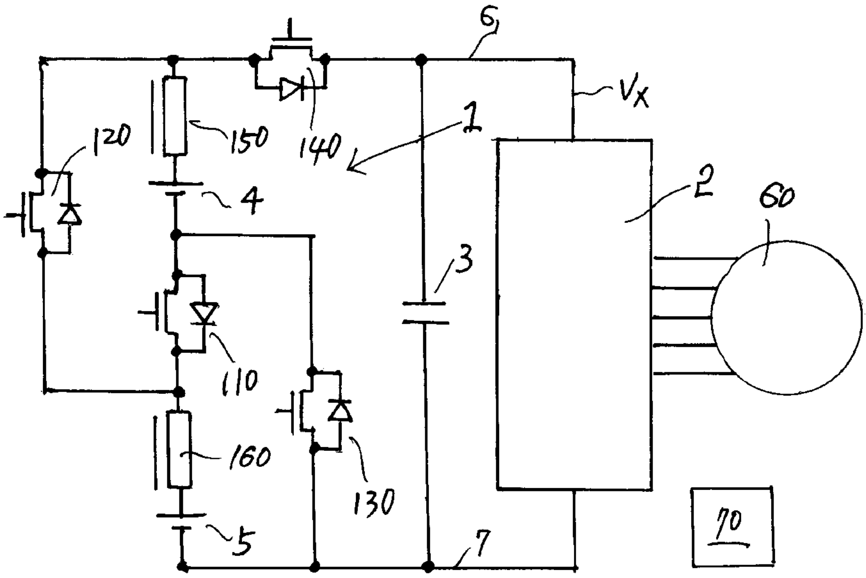
(54) Title: VOLTAGE BOOSTER

[Fig. 3]



(57) Abstract: An object of the invention is to provide a voltage booster capable of boosting an output voltage of a DC voltage source. Two pairs of one reactor and one DC power source are connected in series to each other. Each pair is short circuited by each parallel switch. A power loss of the PWM-switched parallel switch is decreased. A series switch for connecting two pairs can be provided. In another case, a voltage booster for applying a boost voltage to a power converter driving a switched reluctance motor consists of an output switch and a smoothing capacitor in order to accumulate a residual magnetic energy of the switched reluctance motor. The rising-up and the falling-down of phase currents of the switched reluctance motor becomes quickly.

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Description

Title of Invention: VOLTAGE BOOSTER

Cross-Reference to Related Application

[0001] This application claims benefit, under 35 U.S.C.119, from:
PCT/JP2010/006167 filed on Oct/18/2010, BOOST DC-TO-DC CONVERTER AND SWITCHED RELUCTANCE MOTOR POWERED WITH THE SAME and PCT/JP2010/006674 filed on Nov/12/2010, BOOST DC-TO-DC CONVERTER AND POWER CONVERTER POWERED BY THE SAME, the entire content of which is incorporated herein reference.

Background of Invention

[0002] 1. Field of the Invention
The present invention relates to a voltage booster capable of applying a boosted voltage to an electric load, for example a motor-driving circuit including an inverter or a power converter, which drives an electric rotating machine.

[0003] 2. Description of the Related Art
It is desirable to boost a DC voltage applied to an electrical load such as an electric motor. Especially, the inverter for driving a synchronous motor or an asynchronous motor and the power converter for driving a switched reluctance motor need to boost a battery voltage, when the motors are provided for a variable-speed application such as a traction motor of an electric vehicle or a hybrid vehicle.

[0004] Because a motor current is decreased at a high speed range, if a DC link voltage applied to the inverter or the power converter is constant. Moreover, the switched reluctance motor (SRM) needs to increase and decrease phase currents quickly. The phase currents of the SRM rises up and falls down quickly, when the DC link voltage applied to the power converter is increased.

[0005] Figure 1 shows a voltage booster 200, which is well-known as a chopper type DC/DC converter. The voltage booster 200 boosts a battery voltage of the battery 100. The boosted DC link voltage Vx is applied to a motor-driving circuit 300 and a smoothing capacitor 400. The chopper type DC/DC converter consists of a reactor 201, an output switch 202 and a parallel switch 203. The motor-driving circuit 300 consisting of the multi-phase inverter or the multi-phase asynchronous power converter applies a multi-phase voltage to a synchronous motor or an asynchronous motor or a switched reluctance motor, which is not illustrated.

[0006] Figure 2 shows a parallel type voltage booster proposed in Japan Unexamined Patent Publication No. JPA 2004/234476. A battery voltage of battery 100 is boosted by a dual chopper type DC/DC converter 600. A first chopper consists of a reactor 601, a parallel switch 604 and an output switch 605. A second chopper consists of a reactor

602, a parallel switch 603 and an output switch 606. Two boost choppers connected in parallel apply two boost voltages to the motor-driving circuit 300 alternately. Ripple of the boosted DC link voltage Vx is reduced.

Citation List

Patent Literature

[0007] PTL 1: Japan Unexamined Patent Publication JPA 2004/234476

Summary of Invention

[0008] An object of the invention is to provide a voltage booster capable of boosting an output voltage of a DC power source for applying an increased voltage to an electrical load.

[0009] As for a first aspect of the invention, a voltage booster has at least two pairs consisting of a reactor and a DC power source each. Each parallel switch is connected in parallel to each pair in order to short-circuit each pair. The short-circuit current has an opposite direction to an output current of the voltage booster. Accordingly, a power loss of the PWM-switched parallel switches of the voltage booster is reduced largely.

[0010] According to another preferred embodiment, a first middle voltage mode (C) and a second middle voltage mode (D) alternately. The parallel switch (120) is turned on, and the parallel switch (130) is turned off, in the first middle voltage mode (C). The parallel switch (120) is turned off, and the parallel switch (130) is turned on, in the second middle voltage mode (D). Accordingly, a power loss of the parallel switches is reduced largely.

[0011] According to another preferred embodiment, the voltage booster further has a high voltage mode (A) and a low voltage mode (B) alternately. The parallel switches (120 and 130) are turned off in the high voltage mode (A). The parallel switches (120 and 130) are turned on in the low voltage mode (B). Accordingly, the voltage booster outputs a high voltage.

[0012] According to another preferred embodiment, the voltage booster has an alternative switching mode and an overlapped switching mode. Turned-on periods of the parallel switches are executed alternately in the alternative switching mode. Turned-on periods of the parallel switches are overlapped in the overlapped switching mode.

[0013] According to another preferred embodiment, the DC power source consists of a sun cell and a capacitor. Accordingly, the sun cell and the capacitor, which are essentially variable DC voltage source, can output a constant voltage.

[0014] According to another preferred embodiment, the voltage booster further has a series switch (110) connected between the first pair and the second pair for connecting the first pair and the second pair in series. The first parallel switch (120) is connected in parallel to the first pair via the series switch (110). The second parallel switch (130) is connected in parallel to the second pair via the series switch (110). Accordingly, the boost converter can output either one of two constant values of the DC voltage without switching. Furthermore, the voltage booster, which is a boost type DC-to-DC converter, can change a variable DC voltage smoothly in the wide range with less switching loss.

[0015] According to another preferred embodiment, the voltage booster has a series connection stage (A), a parallel connection stage (B) and a short-circuit stage (C, E and F). The stage (A) has the turned-on (closed) series switch (110) and the turned-off (opened) parallel switches (120) and (130). The stage (B) has the turned-off series switch (110) and the turned-on parallel switches (120) and (130). The short-circuit stage (C, E and F) has at least one of the short-circuited first pair and the short-circuited second pair. Accordingly, a plurality of the boost mode can be executed by selecting of the above stages.

[0016] According to another preferred embodiment, the series stage (A) and the short-circuit stage (C, E and F) are executed alternately. As the result, the boost converter can apply a high boost voltage with less switching loss.

[0017] According to another preferred embodiment, the parallel stage (B) and the short-circuit stage (C, E and F) are executed alternately. As the result, the boost converter can apply a low boost voltage with less switching loss.

[0018] As for a second aspect of the invention, a voltage booster with an output switch (140) and a smoothing capacitor (3) applies a boosted DC voltage to a power converter for driving a switched reluctance motor. The output switch (140) is connected in series to the power converter (2) and a DC power source (4). The smoothing capacitor (3) is connected in parallel to the power converter (2). The power converter (2) has a predetermined transient period (Pt) when the power converter (2) starts to output a free-wheeling current, which is a recovery current generated by a residual magnetic energy accumulated in the switched reluctance motor. The output switch (140) is opened in the transient period (Pt) in order to accumulate the residual magnetic energy of the switched reluctance motor (60) in the smoothing capacitor (3). Accordingly, free-wheeling currents of the switched reluctance motor can be decreased quickly. Moreover, phase currents can rise up quickly, because the DC link voltage applied to the power converter is increased.

[0019] According to a preferred embodiment, the output switch consists of an output switch of a chopper type DC-to-DC converter for boosting the DC power source. As the result, the voltage booster becomes simple.

Brief Description of Drawings

[0020] [fig.1]Figure 1 is a circuit topology configuration showing a conventional single chopper type DC-to-DC boost converter for driving a motor-driving circuit.

[fig.2]Figure 2 is a circuit topology configuration showing a conventional dual chopper type DC-to-DC boost converter for driving a motor-driving circuit.

[fig.3]Figure 3 is a circuit topology configuration showing a motor-driving-apparatus of a first embodiment.

[fig.4]Figure 4 is a circuit topology configuration showing a series stage of the boost converter shown in Figure 3.

[fig.5]Figure 5 is a circuit topology configuration showing a short-circuited stage of the boost converter shown in Figure 3.

[fig.6]Figure 6 is a circuit topology configuration showing a parallel stage of the boost converter shown in Figure 3.

[fig.7]Figure 7 is a circuit topology configuration showing an open stage of the boost converter shown in Figure 3.

[fig.8]Figure 8 is a circuit topology configuration showing one partial short-circuited stage of the boost converter shown in Figure 3.

[fig.9]Figure 9 is a circuit topology configuration showing another partial short-circuited stage of the boost converter shown in Figure 3.

[fig.10]Figure 10 is a timing chart showing a DC link voltage applied by the boost converter shown in Figure 3.

[fig.11]Figure 11 is a timing chart showing a DC link voltage applied by the conventional boost converter shown in Figure 1.

[fig.12]Figure 12 is a timing chart showing a DC link voltage applied by the conventional series-parallel connection circuit shown in Figure 2.

[fig.13]Figure 13 is a circuit topology configuration showing a motor-driving-apparatus of a second embodiment.

[fig.14]Figure 14 is a circuit topology configuration showing a high voltage mode (A) of the second embodiment.

[fig.15]Figure 15 is a circuit topology configuration showing a low voltage mode (B) of the second embodiment.

[fig.16]Figure 16 is a circuit topology configuration showing a first middle voltage mode (C) of the second embodiment.

[fig.17]Figure 17 is a circuit topology configuration showing a second middle voltage mode (D) of the second embodiment.

[fig.18]Figure 18 is a timing chart showing waveforms of gate voltages and the DC link voltage Vx in the second embodiment shown in Figure 13.

[fig.19]Figure 19 is a timing chart showing waveforms of gate voltages and the DC link voltage Vx in the second embodiment shown in Figure 13.

[fig.20]Figure 20 is a circuit topology configuration showing a motor-driving-apparatus of a third embodiment.

[fig.21]Figure 21 is a schematic cross-section of a Hendershot type five-phase switched reluctance motor employed in the third embodiment.

[fig.22]Figure 22 is a schematic cross-section of a Hendershot type five-phase switched reluctance motor employed in the third embodiment.

[fig.23]Figure 23 is a schematic cross-section of a Hendershot type five-phase switched reluctance motor employed in the third embodiment.

[fig.24]Figure 24 is a schematic cross-section of a Hendershot type five-phase switched reluctance motor employed in the third embodiment.

[fig.25]Figure 25 is a schematic cross-section of a Hendershot type five-phase switched reluctance motor employed in the third embodiment.

[fig.26]Figure 26 is a timing chart of the third embodiment.

[fig.27]Figure 27 is a timing chart showing a fourth embodiment.

[fig.28]Figure 28 is a circuit topology configuration showing a first arranged embodiment of the fourth embodiment.

[fig.29]Figure 29 is a circuit topology configuration showing a second arranged embodiment of the fourth embodiment.

[fig.30]Figure 30 is a circuit topology configuration showing a fifth embodiment.

[fig.31]Figure 31 is a timing chart showing a strong lighting mode of the fifth embodiment.

[fig.32]Figure 32 is a timing chart showing a normal lighting mode of the fifth embodiment.

[fig.33]Figure 33 is a timing chart showing a low lighting mode of the fifth embodiment.

[fig.34]Figure 34 is a circuit topology configuration showing a sixth embodiment.

Detailed Description of Preferred Embodiments

[0021] (A first embodiment)

Figure 3 shows a circuit topology of a motor-driving apparatus of the first embodiment. The motor-driving apparatus drives a motor 60, for example a switched reluctance motor-generator (SRMG). The motor-driving apparatus consists of a boost chopper type DC-to-DC converter 1, a motor-driving circuit 2 and a smoothing capacitor 3. The motor-driving circuit 2 consists of a power converter for driving the switched reluctance motor 60.

[0022] Motor-driving circuit 2 can consist of an inverter for driving a synchronous motor or an asynchronous motor. The boost chopper type DC-to-DC converter 1 called the voltage booster, boosts battery voltages Vb of two batteries 4 and 5, and applies a DC link voltage Vx to power converter 2 and smoothing capacitor 3. Power converter 2 applies a multi-phase voltage to a motor 60.

[0023] Voltage booster 1 with two boost choppers consists of a series switch 110, parallel switches 120 and 130 and an output switch 140. The voltage booster 1, which is the DC-to-DC converter 1, has a first reactor 150 and a second reactor 160. The first boost chopper consists of the reactor 150 and the switches 110, 120 and 140. The second boost chopper consists of the reactor 160 and the switch 110, 130 and 140. As known well, voltage booster 1 can employ a diode instead of the output switch 140, if the motor 60 is not driven as a generator. Voltage booster 1 outputs a DC link voltage Vx to power converter 2 and smoothing capacitor 3 via a pair of DC link lines 6 and 7 consisting of a high potential line 6 and a low potential line 7.

[0024] Operation of voltage booster 1 is explained referring to Figures 4-9. Figures 4-9 show six connection states of the voltage booster 1. Batteries 4 and 5 have 125V each. Figure 4 shows a series connection state A. In the state A, parallel switches 120 and 130 are turned off, and series switch 110 is turned on. Output switch 140 should be turned on. A diode can be employed as the output switch 140, if voltage booster 1 is one-way type. DC link voltage Vx becomes 250 V or more than 250V, because reactors 150 and 160 connected in series to each other have magnetic energies and output voltages each.

[0025] Figure 5 shows a full short-circuit state C. In the state C, three switches 110, 120 and 130 are turned on. The output switch 140 is turned off, if the output switch 140 is a transistor instead of a diode. Currents of the reactors 150 and 160 are increased, and reactors 150 and 160 accumulate magnetic energies. Figure 6 shows a parallel connection state B. In the state B, parallel switches 120 and 130 are turned on, and series switch 110 is turned off. Output switch 140 should be turned on, if the output switch 140 is a transistor instead of a diode. DC link voltage Vx becomes 125V or more than 125V, because reactors 150 and 160 connected in parallel to each other has magnetic energies and has voltages each.

[0026] Figure 7 shows a full-opened connection state D. In the state D, three switches 110, 120 and 130 are turned off. By the turning-off of three switches 110, 120 and 130 and the output switch 140, the battery voltage is separated safely. Figure 8 shows a first half-short-circuit connection state E. In the state E, parallel switch 120 and series switch 110 are turned on, and parallel switch 130 is turned off. Output switch 140 can be turned on. DC link voltage Vx becomes 125V or more than 125V by reactor 160 and battery 5.

[0027] Reactor 150 accumulates magnetic energy. It is important that magnetizing of reactor 150 and demagnetizing of reactor 160 are executed simultaneously. Moreover, a free-wheeling current of battery 4 and a boost current of battery 5 have opposite directions to each other in parallel switch 120, when the boost converter outputs the boost current. As the result, the resistive power loss of parallel switch 120 is reduced largely.

[0028] Figure 9 shows a second half-short-circuit connection state F. In the state F, parallel switch 130 and series switch 110 are turned on, and parallel switch 120 is turned off. DC link voltage Vx becomes 125V or more than 125V by reactor 150 and battery 5. Reactor 160 accumulates magnetic energy. It is important that magnetizing of reactor 160 and demagnetizing of reactor 150 are executed simultaneously. Moreover, a free-wheeling current of battery 5 and a boost current of battery 4 have opposite directions to each other in parallel switch 130, when the boost converter outputs the current. As the result, the resistive power loss of parallel switch 130 is reduced largely.

[0029] A plurality of the states selected in the states A-F can be executed alternately or in turn for operating a selected one of boost modes. In one high boost mode, the states A and C are operated alternately with a predetermined career frequency. A boost ratio is controlled by changing a period ratio, a PWM duty ratio, between the states A and C. In one low boost mode, the states B and C are operated alternately with a predetermined career frequency. The boost ratio is controlled by changing a period ratio, the PWM duty ratio, between the states B and C.

[0030] In another high boost mode, the states E, A, F and A are operated in turn with a predetermined career frequency. In another low boost mode, the states E, B, F and B are operated in turn with a predetermined career frequency. In the states E and F, the current ripple is reduced, because one reactor accumulates the magnetic energy, and another reactor consumes the magnetic energy. The boost ratio can be controlled by changing the PWM duty ratio of parallel switches 120 and 130.

[0031] Figure 10 is a timing chart showing DC link voltage Vx changed by changing the modes or the states. In a period T1 employing the parallel connection state B, DC link voltage Vx becomes 125V. In a period T3 employing the series connection state A, the DC link voltage Vx is 250V. In a period T2 between the periods T1 and T3, the low boost mode is employed. DC link voltage Vx becomes an intermediate value between 125V and 250V. In a period T4, the high boost mode is employed. DC link voltage Vx becomes more than 250V.

[0032] Figure 11 is a timing chart showing DC link voltage Vx applied by the conventional boost converter shown in Figure 1. Figure 12 is a timing chart showing the voltage Vx applied by the conventional series-parallel-changing circuit. Consequently, the voltage booster 1 shown in Figure 3 can apply either one of two constant values 125V and 250V of the DC link voltage Vx without switching of voltage booster 1. Furthermore, voltage booster 1 can change DC link voltage Vx smoothly and widely. Switching loss and current ripple of the voltage booster 1 are reduced by means of selecting the best boost mode of the voltage booster 1 in accordance with a value of DC link voltage Vx. For example, resistive power loss of the boost converter becomes 25% in the parallel state B, because the boost currents flow in parallel.

[0033] (A second embodiment)

Figure 13 shows a circuit topology of a motor-driving apparatus of the second embodiment. The motor-driving apparatus drives a switched reluctance motor-generator (SRMG) 60. The motor-driving apparatus consists of a boost chopper type DC-to-DC converter 1, a motor-driving circuit 2 and a smoothing capacitor 3. The motor-driving circuit 2 consists of a power converter for driving the switched reluctance motor 60. Motor-driving circuit 2 can consist of an inverter for driving a synchronous motor or an asynchronous motor. The boost chopper type DC-to-DC converter 1, the voltage booster 1, can boost each battery voltage Vb of batteries 4 and 5, and applies a boosted DC link voltage Vx to power converter 2 and smoothing capacitor 3. Power converter 2 applies a five-phase voltage to five-phase SRMG 60.

[0034] Voltage booster 1 has parallel switches 120 and 130, an output switch 140 and reactors 150 and 160. The reactors 150 and 160 have a predetermined value of inductance each. Reactors 150 and 160, batteries 4 and 5 and the output switch 140 are connected in series to each other. The parallel switch 120 is connected in parallel to a pair of the battery 4 and the reactor 150 connected in series.

[0035] The parallel switch 130 is connected in parallel to a pair of the battery 5 and the reactor 160 connected in series. The output switch 140 is connected to a positive DC terminal of the motor-driving circuit 2 via a high potential DC link 6. Reactor 160 is connected to a negative DC terminal of the motor-driving circuit 2 via a low potential DC link 7. After all, voltage booster 1 are connected to motor-driving circuit 2 via a high potential DC link 6 and a low potential DC link 7. A controller 70 controls voltage booster 1 and motor-driving circuit 2.

[0036] Operation of voltage booster 1 is explained referring to Figures 14-19. Batteries 4 and 5 have 125V each. Figure 14 shows a high voltage mode (A). Parallel switches 120 and 130 are opened. Voltage booster 1 outputs 250V + V150 + V160. Reactor 150 has a voltage V150. Reactor 160 has a voltage V160. The output switch 140 is turned on. Figure 15 shows a low voltage mode (B). Parallel switches 120 and 130 are closed. Voltage booster 1 outputs 0V. The output switch 140 is turned off.

[0037] Figure 16 shows a first middle voltage mode (C). Parallel switch 120 is closed. Parallel switch 130 is opened. The output switch 140 is turned on. Battery 5 and reactor 160 output 125V + V160. Reactor 150 accumulates a magnetic energy. It is important that a current I1 flowing through battery 5 and reactor 160 has an opposite direction to a magnetizing current I2 flowing through battery 4 and reactor 150, when voltage booster 1 supplies a motor current to motor-driving circuit 2. Accordingly, a current difference I1-I2 passing through parallel switch 120 is decreased.

[0038] Figure 17 shows a second middle voltage mode (D). Parallel switch 130 is closed. Parallel switch 120 is opened. The output switch 140 is turned on. Battery 4 and reactor 150 output 125V + V150. Reactor 160 accumulates a magnetic energy. It is important that a current I2 flowing through battery 4 and reactor 150 has an opposite direction to a magnetizing current I1 flowing through battery 5 and reactor 160, when voltage booster 1 supplies a motor current to motor-driving circuit 2. Accordingly, a current difference I1-I2 passing through parallel switch 130 is decreased.

[0039] Figure 18 is a timing chart showing an alternative switching mode for outputting a low average value of boosted voltage Vx. A gate voltage VA is applied to a gate of parallel switch 120. A gate voltage VB is applied to a gate of parallel switch 130. The gate voltage VA and the gate voltage VB are applied alternately. Accordingly, the DC link voltage Vx across the power converter 2 becomes small relatively and has low ripples relatively. Moreover, switching power losses of the parallel switches 120 and 130 becomes very small, because a current I120 of the parallel switch 120 and a current I130 of the parallel switch 130 become very small in comparison with an overlapped switching mode shown in Figure 19.

[0040] Figure 19 is a timing chart showing the overlapped switching mode for outputting a high voltage. Turned-on periods of two parallel switches 120 and 130 are overlapped. Both of gate voltages VA and VB are applied for same periods. Accordingly, the DC link voltage Vx has become large relatively and has high ripples relatively. Consequently, amplitude and the ripples of the boosted voltage Vx can be controlled by means of controlling a phase difference and PWM duty ratio of gate voltages VA and VB, which are PWM-switched.

[0041] (A third embodiment)

Figure 20 shows a circuit topology of a motor-driving apparatus of the third embodiment. The motor-driving circuit 2 consists of a five-phase power converter for driving the Hendershot type five-phase SRMG. This five-phase power converter is explained in PCT/JP2010/006674 applied by the inventor. Figures 21-25 are schematic configurations for showing five angular positions of the five-phase SRM with ten stator poles and four U-shaped rotor pole pairs. The five-phase SRM has two sets of five phase windings 401-405 constituting a stator winding. Each of five phase windings 401-405 is wound on each of stator poles A-E of a stator 201 in turn.

[0042] Five-phase power converter 2 consists of six transistors 201-206 and six freewheeling diodes 301-306. Transistors can be employed instead of the freewheeling diodes 301-306. The upper transistors 201, 203 and 205 connect the high potential DC link line 6 and the phase windings 401, 403 and 405 respectively. The lower transistors 202, 204 and 206 connect the low potential DC link line 7 and the phase windings 402, 404 and 405 respectively. The other ends of phase windings 401-405 are connected to a neutral line N. Accordingly, five phase windings 401-405 has a star configuration connection. It is important that the Hendershot type five-phase SRM can be driven by the simple five-phase power converter with star configuration connection.

[0043] The lower freewheeling diodes 301, 303 and 305 are connected to one ends of phase windings 401, 403 and 405 respectively. The upper freewheeling diodes 302, 304 and 306 are connected to one ends of phase windings 402, 404 and 406 respectively. Each of transistors switched synchronously can be connected to each of freewheeling diodes 301-306 in parallel due to reduce the known diode voltage drop. Voltage booster 1 shown in Figure 13 applies boosted DC link voltage Vx to power converter 2.

[0044] Five-phase 10/8 SRM shown in Figures 21-25 has a stator 9 and a rotor core 10. The stator 9 has two sets of five stator poles A-E connected magnetically to each other with a cylinder-shaped stator core back 90. The rotor core 10 has four U-shaped rotor pole cores 101-104 fixed on an outer circumferential surface of a nonmagnetic cylinder portion 10A press-fixed on an axis 11. Each of U-shaped rotor pole cores 101-104 having two rotor poles 105 each are disposed with a constant circumferential pitch on the outer surface of the rotor core back 10A. Arrangement of ten rotor poles 105 is same as it of the Hendershot's five-phase 10/8 SRM.

[0045] Rotor 10 has two kinds of circumferential rotor pole gaps, which are four narrow gaps and four wide gaps. The narrow gap and the wide gap are disposed alternately between adjacent two rotor poles 105. A circumferential width of the wide rotor pole gap between adjacent two U-shaped rotor poles is about 150% of a circumferential width of the narrow rotor pole gap between adjacent two rotor poles of one U-shaped rotor pole. Each angular position of rotor 10 at each time t1, t2, t3, t4 and t5 is shown in Figures 11-15.

[0046] In Figure 21, transistors 205 and 204 are turned on in a period from t3 to t4. A phase currents Ied is supplied to the phase winding 405 and 404. In Figure 22, transistors 203 and 202 are turned on in a period from t4 to t5. A phase currents Icb is supplied to the phase windings 403 and 402. In Figure 23, transistors 201 and 206 are turned on in a period from t5 to t1. A phase currents Iae is supplied to the phase windings 401 and 405. In Figure 24, transistors 203 and 204 are turned on in a period from t1 to t2. A phase current Icd is supplied to the phase windings 403 and 404.

[0047] In Figure 25, transistors 201 and 202 are turned on in a period from t2 to t3. A phase currents Iab is supplied to the phase winding 401 and 402. It should be considered that the phase current Iae in the period from t5 to t1 flows toward an opposite direction to the phase current Ied in the period from t3 to t4.

[0048] Furthermore, one of upper transistors 201, 203 and 205 and one of lower transistors 202, 204 and 206 are turned on in the same period and turned off in the same period. As the result, an electric potential of the neutral line N is not changed by means of the turning-on and the turning-off of the two transistors at one time. It means that the single-switch-per-phase power converter 2 does not need well-known two split capacitors which are required in a conventional split voltage type converter with the single-switch-per-phase topology.

[0049] In Figures 21-25, dotted lines show the magnetic flux flowing in long paths of the stator core back 90. Real lines show the magnetic flux flowing in short paths. Iron loss of the core back 90 is reduced by the magnetic flux in the long paths of stator core back 90.

[0050] Figure 26 is a timing chart showing five phase voltages Va, Vb, Vc, Vd and Ve applied to five phase windings 401-405 of five-phase SRM. The phase voltage Va is applied to phase winding 401. The phase voltage Vb is applied to phase winding 402. The phase voltage Vc is applied to phase winding 403. The phase voltage Vd is applied to phase winding 404. The phase voltage Ve is applied to phase winding 405.

[0051] Each of the phase voltages Va, Vb, Vc, Vd and Ve is increased in each transient period Pt consisting of current-increasing periods and current-decreasing periods. One constant current period is arranged between one current-increasing period and one current-decreasing period as shown in Figure 26. Each of the phase voltages Va, Vb, Vc, Vd and Ve is increased in each transient period Pt by means of increasing the DC link voltage Vx.

[0052] Consequently, each phase current Iae, Icb, Icd, Iae and Ied can rise up quickly and can fall down quickly. In the other words, the voltage booster 1 increases the DC link voltage Vx in the transient periods Pt. As the result, a motor torque is increased largely. Increasing of the DC link voltage Vx is executed by boosting operation of the boost DC/DC converter 1 explained above.

[0053] (A fourth embodiment)

The fourth embodiment is explained referring to Figure 20 and Figure 27. Figure 27 is a timing chart showing a part of Figure 26. Figure 27 shows waveforms of an inductance L401 of the phase winding 401, an inductance L405 of the phase winding 405, an inductance L403 of the phase winding 403 and an inductance L404 of the phase winding 404. Furthermore, Figure 27 shows phase currents Iae, Iab, Icb and Icd and the DC link voltage Vx.

[0054] The transient period Pt, in which the phase current increases or decreases quickly, is formed from a time point t5 to a time point t51, from a time point t1 to a time point t11 and from a time point t2 to a time point t21. In the transient period Pt, increased phase currents rise up quickly by means of increasing the DC link voltage Vx. Similarly, decreased phase currents, which are freewheeling currents, fall down quickly by means of decreasing the DC link voltage Vx.

[0055] According to this fourth embodiment, the DC link voltage Vx is increased in the transient period Pt by means of the opening of the output switch 140 of voltage booster 1. For example, transistors 203 and 202 are opened, and transistors 201 and 206 are closed, in the transient period Pt from t5 to t51. Furthermore the output switch 140 is closed in the transient period Pt from t5 to t51. Accordingly, the freewheeling current Icb charges the smoothing capacitor 3 quickly in the transient period Pt. As the result, the phase current Iae rises up quickly, and the phase current Icb falls down quickly, by means of the increasing of the DC link voltage Vx across the smoothing capacitor 3 in the transient period Pt from t5 to t51.

[0056] Similarly, the phase current Iae falls down quickly, and the phase current Icd rises up quickly, by means of the closing of the output switch 140 in the transient period Pt from t1 to t11. Similarly, the phase current Icd falls down quickly, and the phase current Iab rises up quickly, by means of the closing of the output switch 140 in the transient period Pt from t2 to t21.

[0057] A waveform of the DC link voltage Vx is shown in Figure 27. The DC link voltage Vx is increased quickly by the freewheeling current in an initial period of the transient period Pt. Then, the DC link voltage Vx is increased quickly by the freewheeling current in an initial period of the transient period Pt. Then, the DC link voltage Vx is decreased. Then, amplitude of the DC link voltage Vx becomes constant by means of PWM-switching of the transistors of the power converter 2 in a constant-current-period Tb. The amplitude of the DC link voltage Vx in a freewheeling period Tf is larger than the amplitude of the DC link voltage Vx in the constant-current-period Tb.

[0058] The output switch 140 of the voltage booster 1 should be turned on, after the DC link voltage Vx is mostly equal to an output voltage of the voltage booster 1. In the constant current period Pc, the closed transistors of the power converter 1 are PWM-switched in order to keep the phase current constant. In generator mode, the phase current is increased quickly when the inductance of the phase winding is in a large range, and the phase current is decreased quickly when the inductance of the phase winding is in a small range, as known well.

[0059] In this embodiment, voltage booster 1 does not need that the parallel switches 120 and 130 are switched with the PWM-switching method. However, it is desirable to operate the PWM-switching of the parallel switches 120 and 130 in accordance with a rotating speed of the SRM. For example, the output voltage should be increased in a high rotation speed range of the SRM.

[0060] An important feature of this embodiment is that the output switch 140 of the voltage booster 1 is opened in the transient period Pt while the freewheeling current of each phase is energized. Accordingly, the freewheeling current of the power converter 2 charges the smoothing capacitor 3 instead of the voltage booster 1. The DC link voltage Vx is increased by means of charging the smoothing capacitor 3. The output switch 140 should be turned on again, after the DC link voltage Vx becomes equal or less than the output voltage of voltage booster 1.

[0061] (A first arranged embodiment)

The first arranged embodiment of the above fourth embodiment is explained referring to Figure 28. In Figure 28, the voltage booster 1 consists of only a pair of the output switch 140 and the smoothing capacitor 3. The output switch 140 connects one battery 4 to the high potential DC link line 6. In this first arranged embodiment, the output switch 140 is opened in the transient period Pt when the freewheeling current flows out from the power converter 2.

[0062] By means of the opening of the output switch 140, the freewheeling current of the power converter 2 charges the smoothing capacitor 3. The DC link voltage Vx is increased in the transient period Pt. As the result, the phase current can rise up quickly, and the phase current can fall down quickly.

[0063] (A second arranged embodiment)

The second arranged embodiment of the above fourth embodiment is explained referring to Figure 29. In Figure 29, the voltage booster 1 consists of only a pair of the output diode 140A and the smoothing capacitor 3. The output diode 140A connects the battery 4 to the high potential DC link line 6. In this second arranged embodiment, the switched reluctance motor (not illustrated) are not operated as the generator, but are operated as the motor.

[0064] (A fifth embodiment)

The fifth embodiment is explained referring to Figure 30. Figure 30 shows a circuit topology of a sun cell power generator with a voltage booster 1 and three sun cells 4A, 4B and 4C. Each of the sun cells 4A, 4B and 4C is a DC power sources for transforming a sun light to a DC voltage. The sun cell power generator has a first generator block A, a second generator block B, a third generator block C, an output switch 140 and a smoothing capacitor 3. The output switch 140 can consist of only one diode.

[0065] The first generator block A consists of sun cell 4A, a reactor 150A and a parallel switch 120A. The second generator block B consists of sun cell 4B, reactor 150B and a parallel switch 120B. The third generator block C consists of sun cell 4C, a reactor 150C and a parallel switch 120C. In the other words, voltage booster 1 shown in Figure 30 is essentially same as the voltage booster 1 shown in Figure 13 except a fact that one more pair of the reactor and the parallel switch is added. The sun cells 4A, 4B and 4C are essentially same as the batteries 4 and 5 shown in Figure 13.

[0066] The generation blocks A, B and C are connected in series to each other. Parallel switch 120A is connected in parallel to a pair of sun cell 4A and reactor 150A, which are connected in series. Parallel switch 120B is connected in parallel to a pair of sun cell 4B and reactor 150B, which are connected in series.

Parallel switch 120C is connected in parallel to a pair of sun cell 4C and reactor

150C, which are connected in series.

[0067] Operation of the sun cell power generator is explained referring to Figures 31-33, which are timing charts showing gate voltages of parallel switches 120A, 120B and 120C. Figure 31 shows a strong lighting mode in a time when sun shine is strong.

The parallel switches 120A, 120B and 120C are turned on in turn. Accordingly, a boost ration of the voltage booster 1 becomes relatively low. Figure 32 shows a medium lighting mode in a time when sun shine is normal. each two of the parallel switches 120A; 120B and 120C are turned on in turn. Accordingly, a boost ratio of the voltage booster 1 becomes middle relatively. Figure 33 shows a low lighting mode in a time when sun shine is low. all of the parallel switches 120A, 120B and 120C are turned simultaneously.

[0068] Accordingly, a boost ration of the voltage booster 1 becomes relatively high. Each PWM-ratio of parallel switches 120A, 120B and 120C are changed in accordance with the strength of the sun light. After all, the changing voltage of the sun cells 4A, 4B and 4C are compensated with the voltage booster 1. It is important that the current Is, which is a magnetizing current of the reactor, when the parallel switch is turned on, has the opposite flow direction in comparison with the generation current of the sun cell. Consequently, PWM-switched parallel switches 120A, 120B and 120C have a small power loss each.

[0069] (A first arranged embodiment)

Referring to the arranged embodiment, electrical double-layer capacitors are employed instead of the sun cells 4A, 4B and 4C shown in Figure 30. The electrical double-layer capacitors have a weak point that a capacitor voltage changes largely in accordance with a value of the accumulated energy. The voltage booster 1 shown in Figure 30 compensates the voltage change without a large power loss of the voltage boosting. In addition, more than three of generator blocks can be connected in series to each other.

[0070] (A sixth embodiment)

The sixth embodiment is explained referring to Figure 30. Figure 34 shows a circuit topology of a motor-driving apparatus with a voltage booster 1. Voltage booster 1 shown in Figure 34 is essentially same as the voltage booster 1 shown in Figure 13. However, voltage booster 1 shown in Figure 34 has a common soft magnetic core on which coils of reactors 150 and 160 are wound. Accordingly, the two coils of reactors 150 and 160 constitute a transformer, too.

Claims

[Claim 1] A voltage booster comprising:
a first pair of a first reactor (150) and a first DC power source (4) connected in series to each other;
a second pair of a second reactor (160) and a second DC power source (5) connected in series to each other;
a first parallel switch (120) connected in parallel to the first pair for short-circuiting the first pair;
a second parallel switch (130) connected in parallel to the second pair for short-circuiting the second pair; and
an output switch (140) connecting the first pair and the first parallel switch (120) to an electrical load in order to output a boosted DC voltage (Vx) from the first pair and the first parallel switch (120) to the electrical load.

[Claim 2] The voltage booster according to claim 1, wherein the voltage booster has a first middle voltage mode (C) and a second middle voltage mode (D) alternately;
the parallel switch (120) is turned on, and the parallel switch (130) is turned off, in the first middle voltage mode (C); and
the parallel switch (120) is turned off, and the parallel switch (130) is turned on, in the second middle voltage mode (D).

[Claim 3] The voltage booster according to claim 1, wherein the voltage booster further has a high voltage mode (A) and a low voltage mode (B) alternately;
the parallel switches (120 and 130) are turned off in the high voltage mode (A); and
the parallel switches (120 and 130) are turned on in the low voltage mode (B).

[Claim 4] The voltage booster according to claim 1, wherein the voltage booster has a series switch (110) connected between the first pair and the second pair for connecting the first pair and the second pair in series;
the first parallel switch (120) is connected in parallel to the first pair via the series switch (110); and
the second parallel switch (130) is connected in parallel to the second pair via the series switch (110);

[Claim 5] The voltage booster according to claim 4, wherein the voltage booster has a series connection stage (A), a parallel connection stage (B) and a

short-circuit stage (C, E and F);
the stage (A) has the closed series switch (110) and the opened parallel switches (120) and (130);
the stage (B) has the opened series switch (110) and the closed parallel switches (120) and (130); and
the short-circuit stage (C, E and F) has at least one of the short-circuited first pair and the short-circuited second pair.

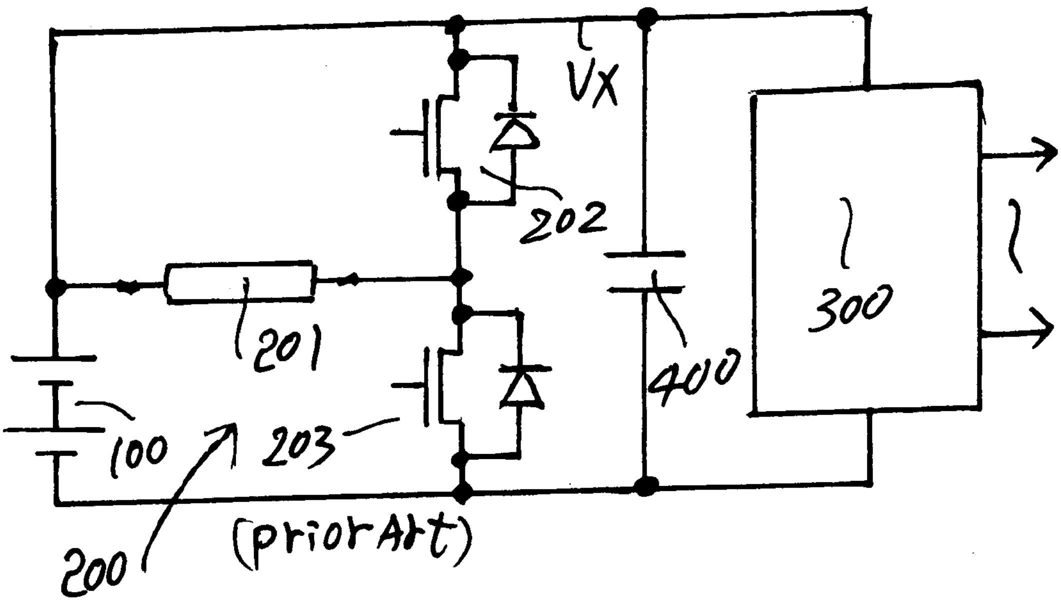
[Claim 6] The voltage booster according to claim 5, wherein the series stage (A) and the short-circuit stage (C, E and F) are executed alternately.

[Claim 7] The voltage booster according to claim 5, wherein the parallel stage (B) and the short-circuit stage (C, E and F) are executed alternately.

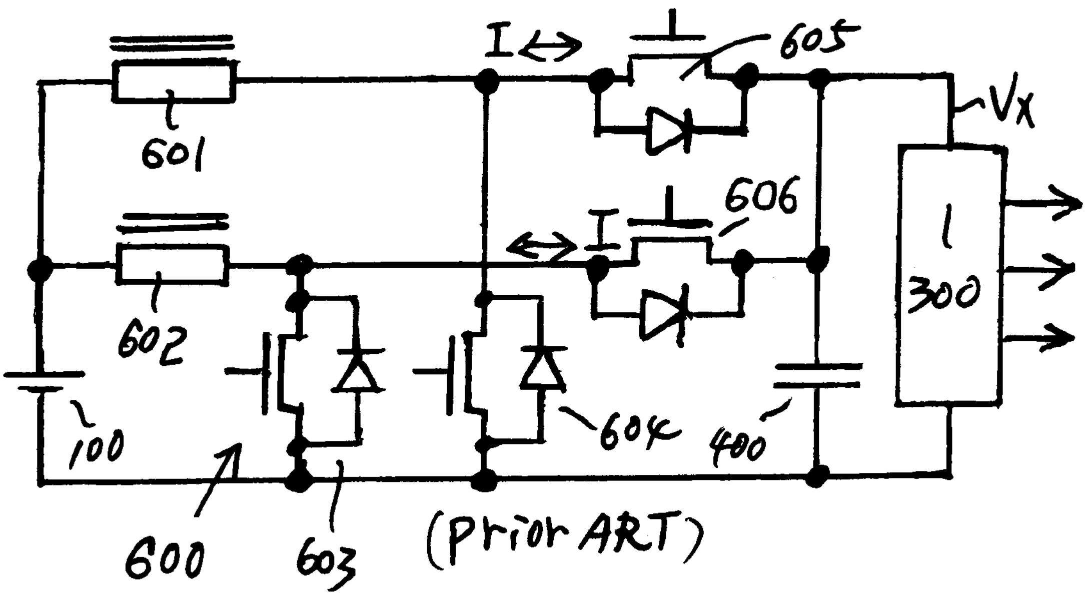
[Claim 8] A voltage booster for applying a boosted voltage to a power converter for driving a switched reluctance motor, wherein the voltage booster includes an output switch (140) and a smoothing capacitor (3);
the output switch (140) is connected in series to the power converter (2) and a DC power source (4);
the smoothing capacitor (3) is connected to the power converter (2) in parallel;
the power converter (2) has a predetermined transient period (Pt) when the power converter (2) starts to output a freewheeling current; and
the output switch (140) is opened in the transient period (Pt) for accumulating a residual magnetic energy of the switched reluctance motor (60) in the smoothing capacitor (3).

[Claim 9] The voltage booster according to claim 8, wherein the output switch consists of an output switch of a chopper type DC-to-DC converter for boosting the DC power source.

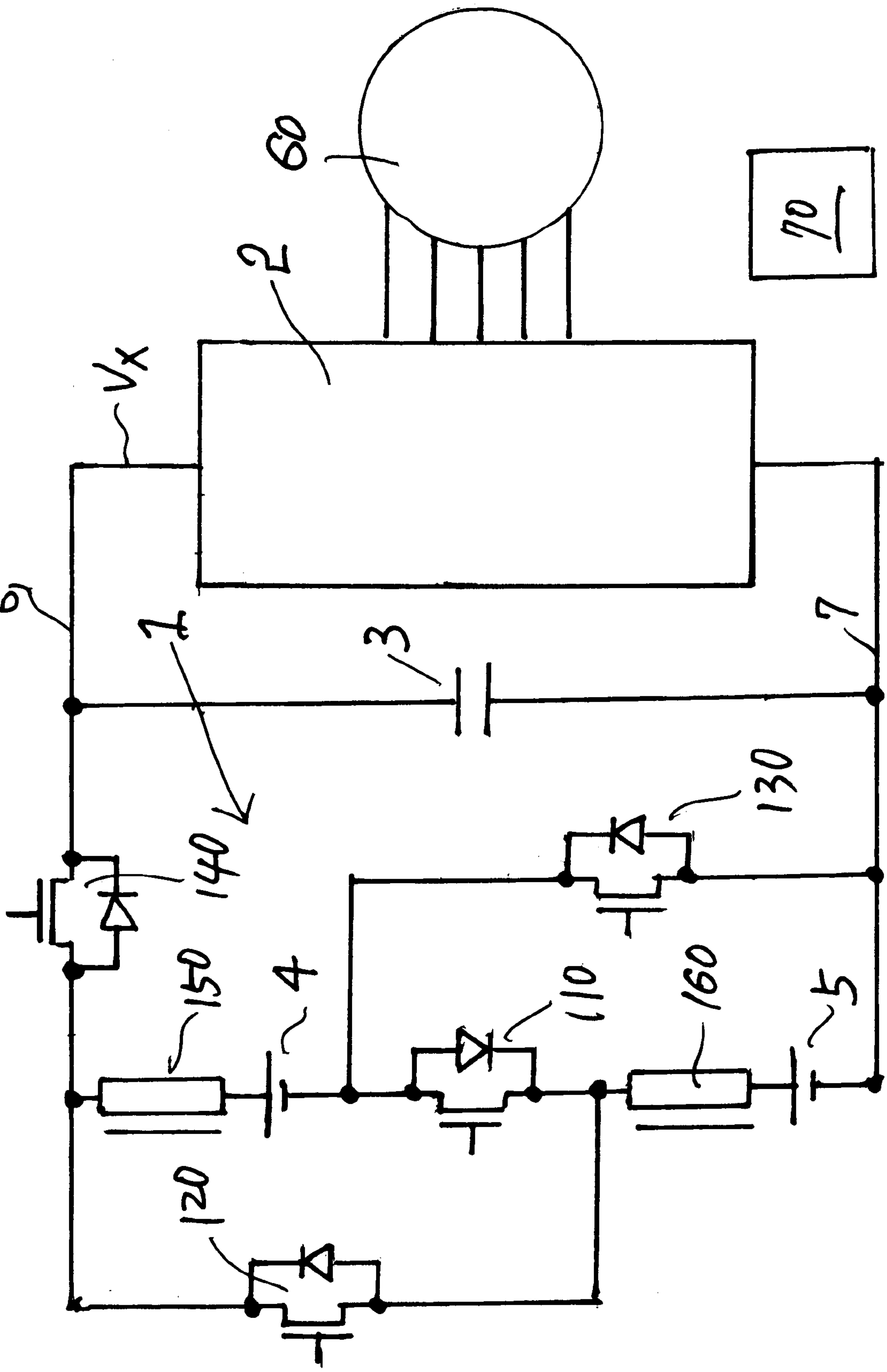
[Fig. 1]


Vx
202
201
300
400
100
203
200
(priorArt)

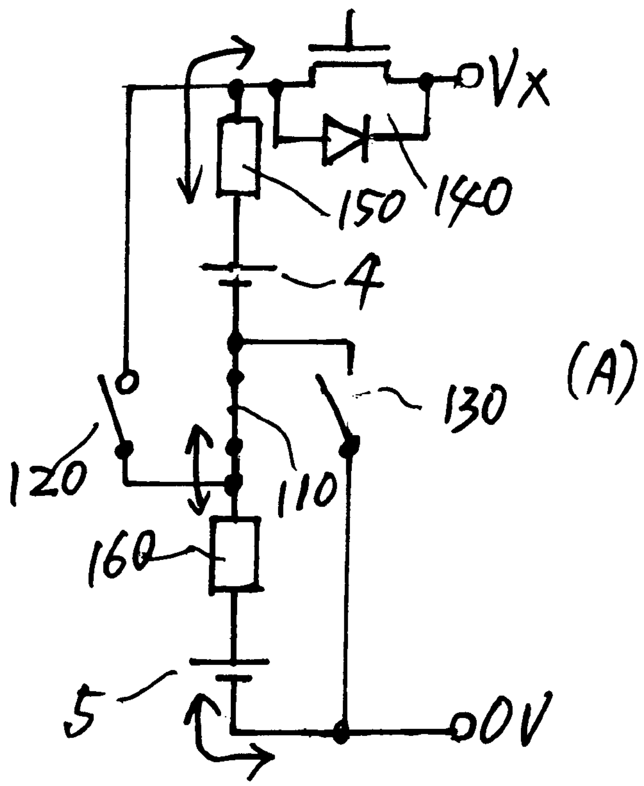
[Fig. 2]


I
605
Vx
601
606
I
602
300
100
604
400
600
603
(PriorART)

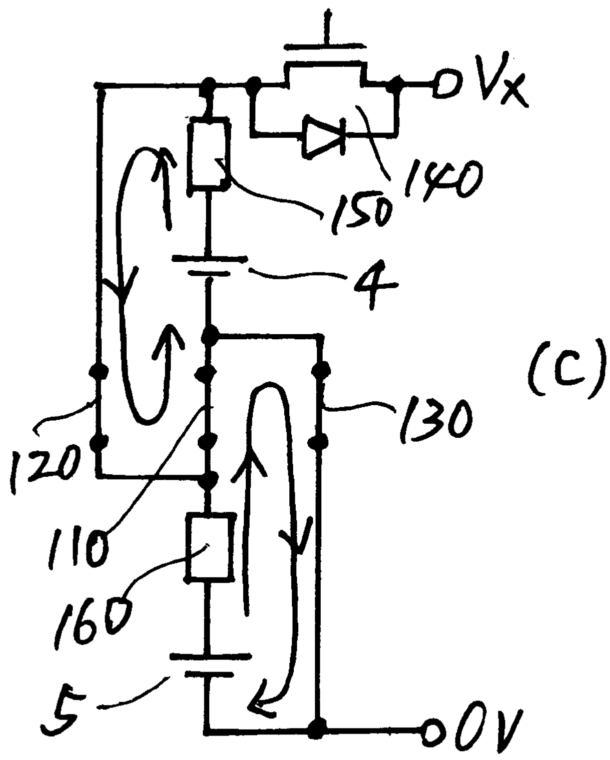
[Fig. 3]



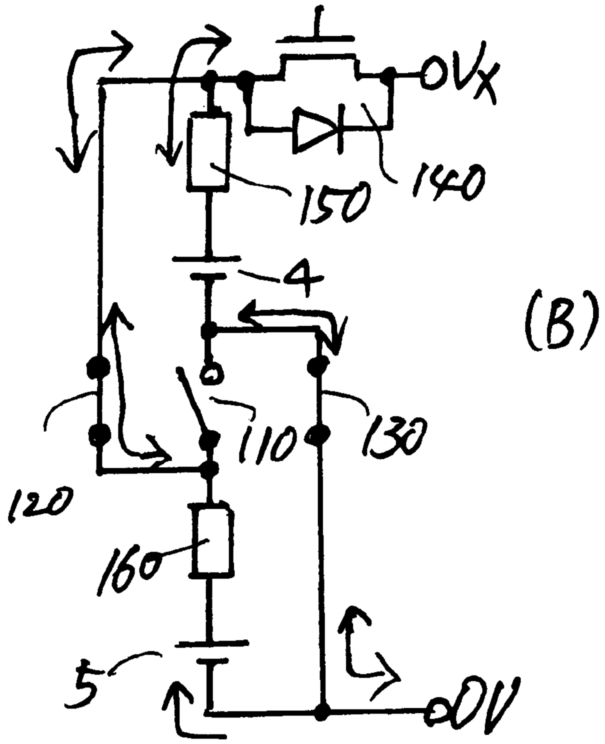
[Fig. 4]


Vx
150
140
4
(A)
130
120
110
160
5
0V

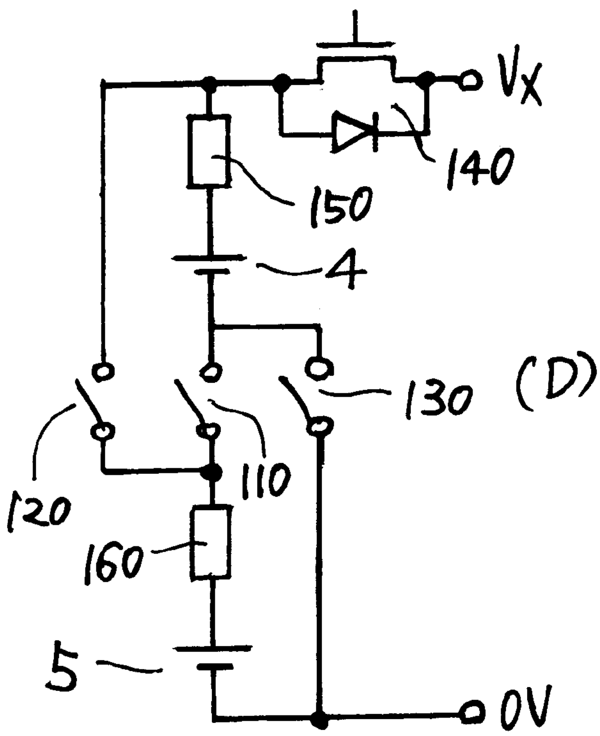
[Fig. 5]


Vx
150
140
4
(C)
130
120
110
160
5
0V

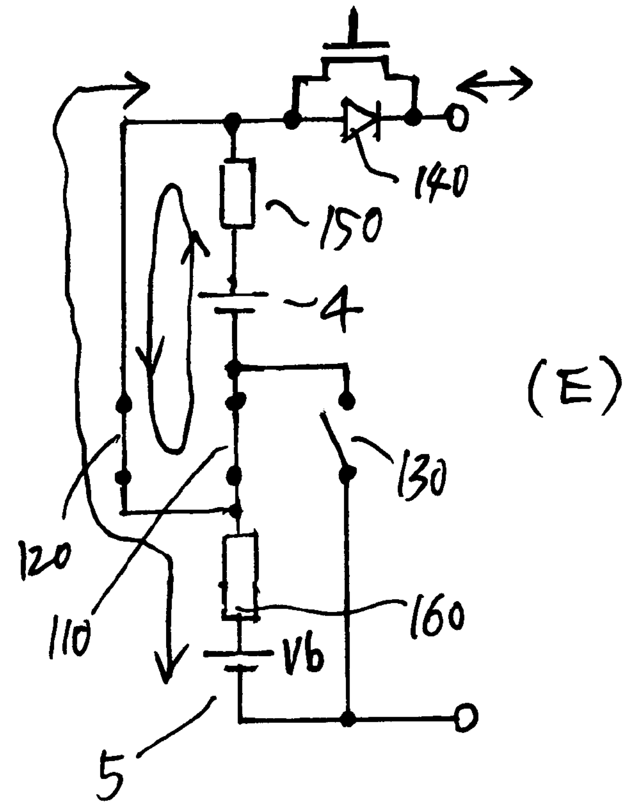
[Fig. 6]


OVx
140
150
4
(B)
110
130
120
160
5
OV

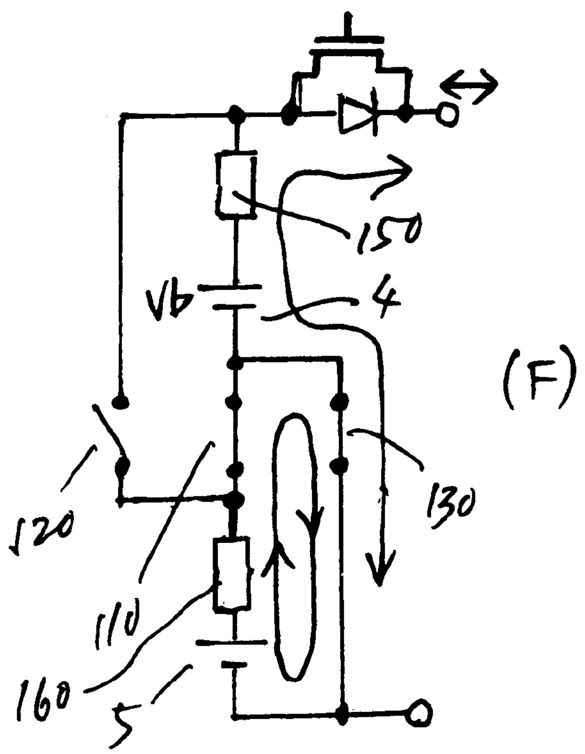
[Fig. 7]


Vx
140
150
4
130
(D)
120
110
160
5
OV

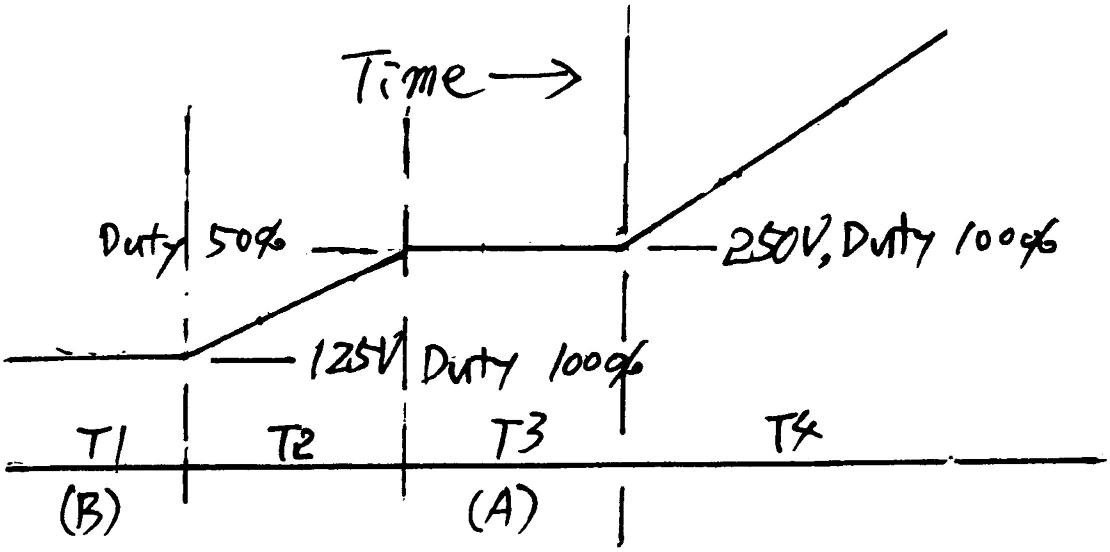
[Fig. 8]



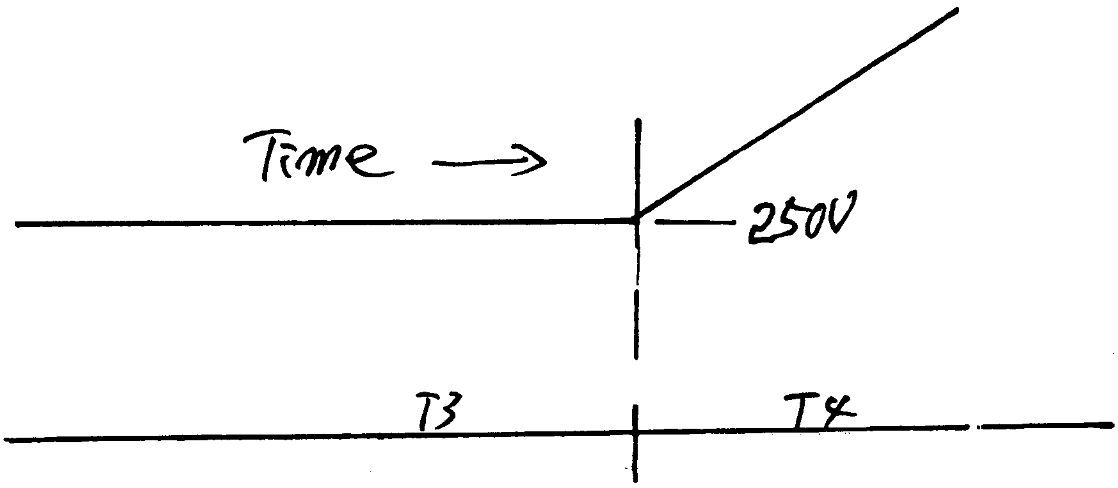
[Fig. 9]



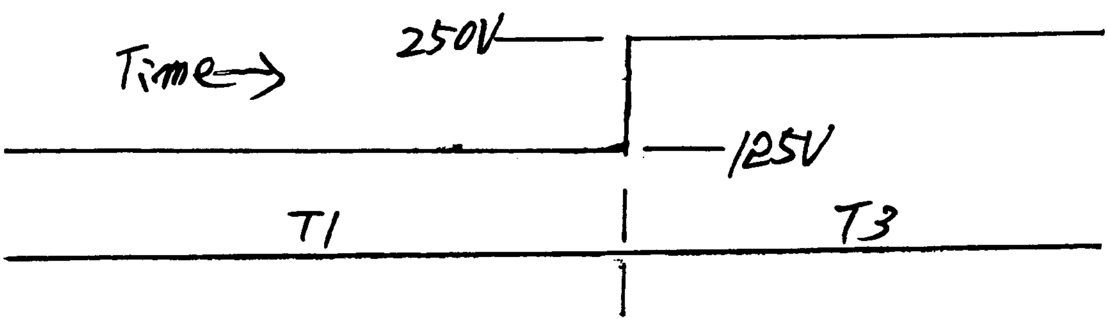
[Fig. 10]



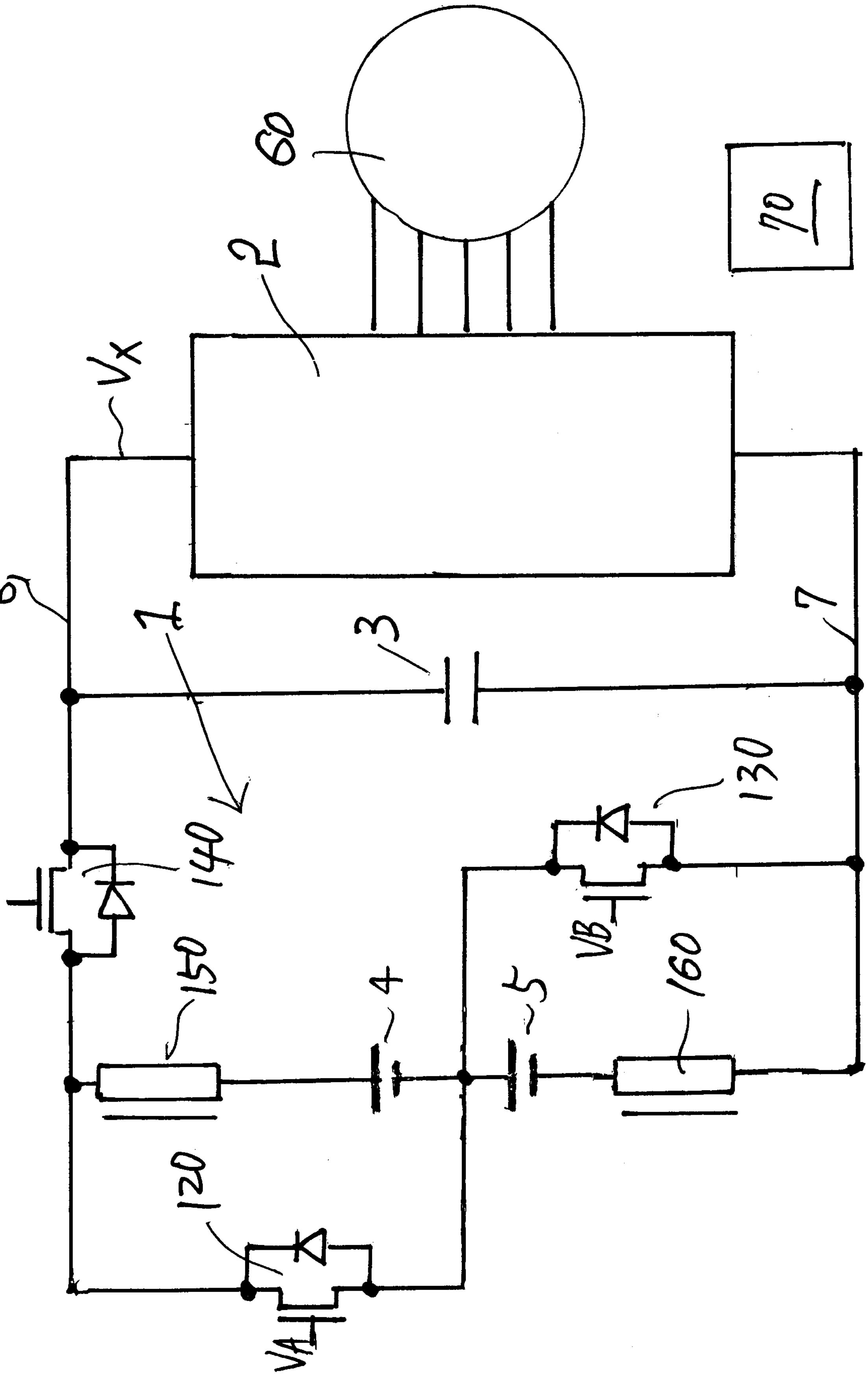
[Fig. 11]



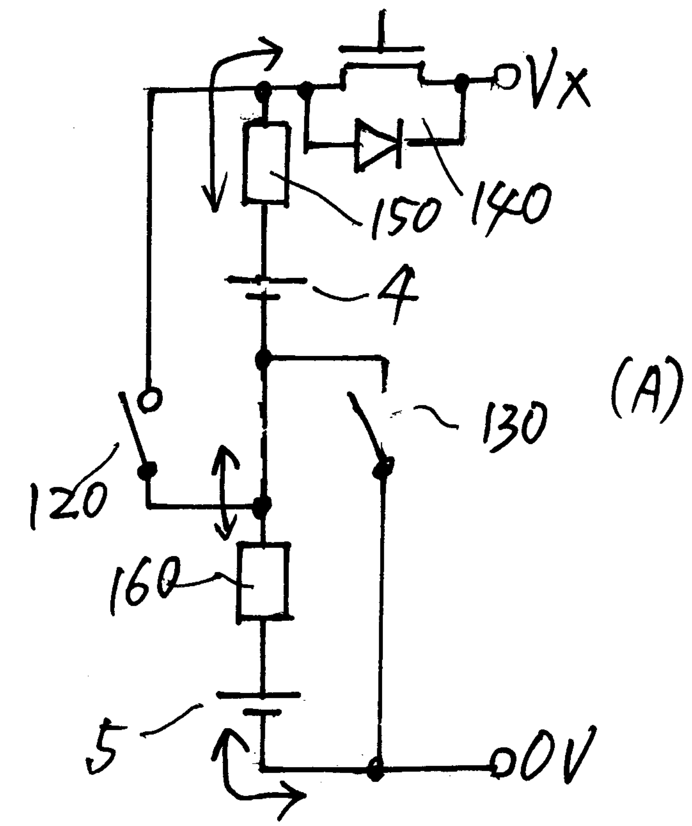
[Fig. 12]



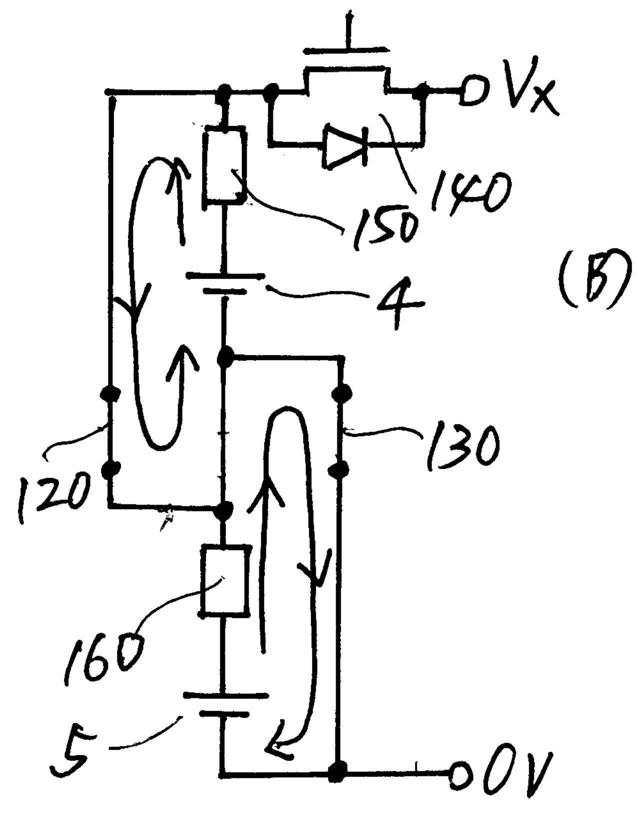
[Fig. 13]



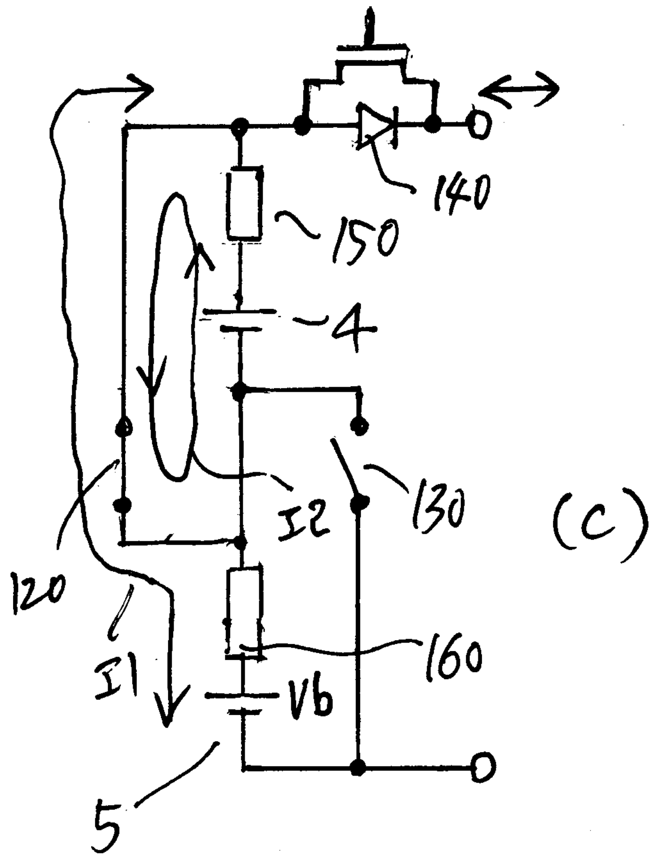
[Fig. 14]



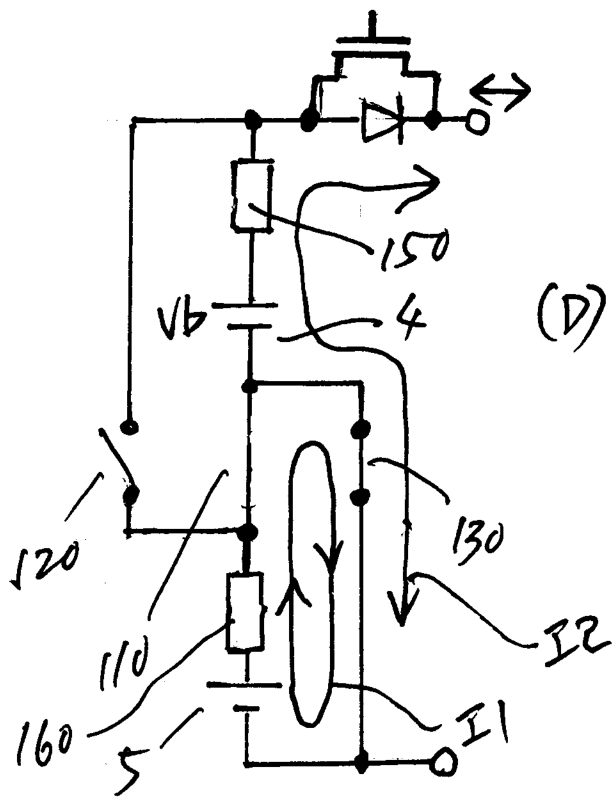
[Fig. 15]



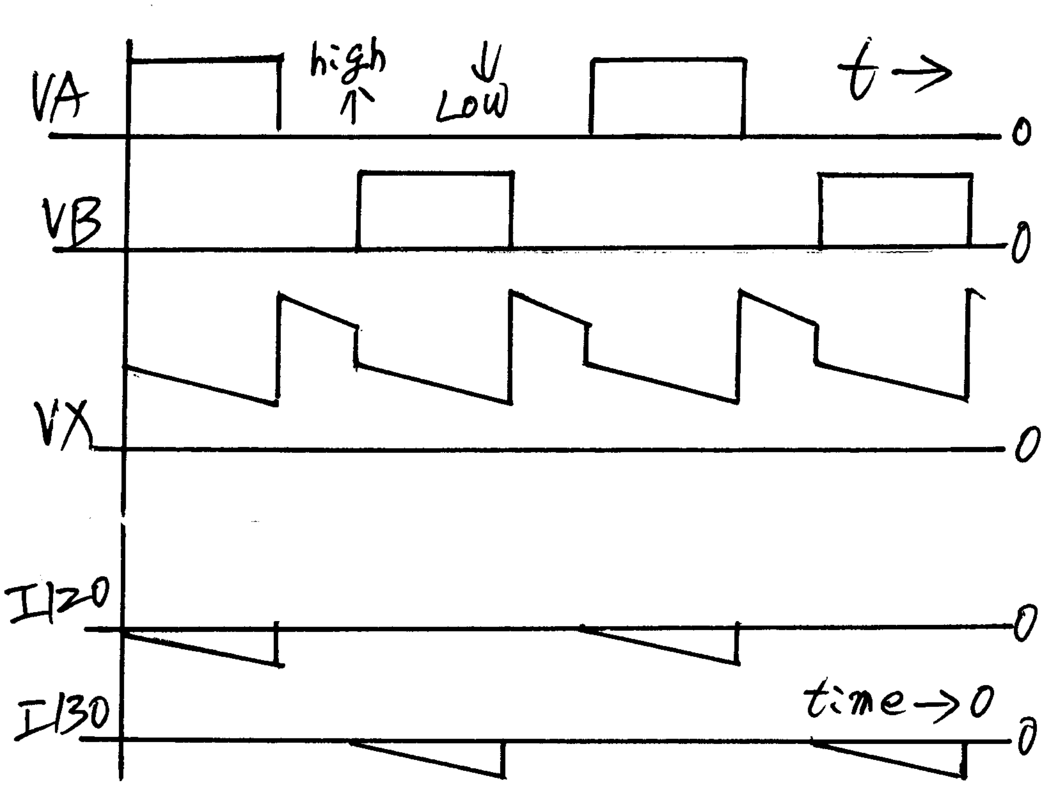
[Fig. 16]



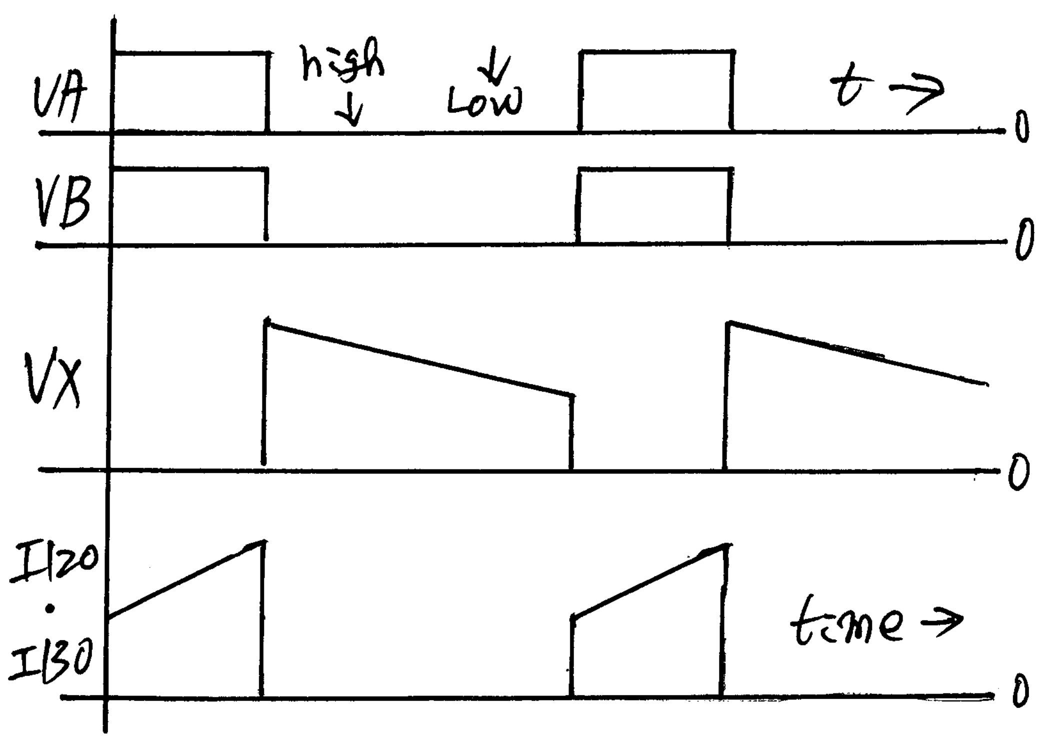
[Fig. 17]



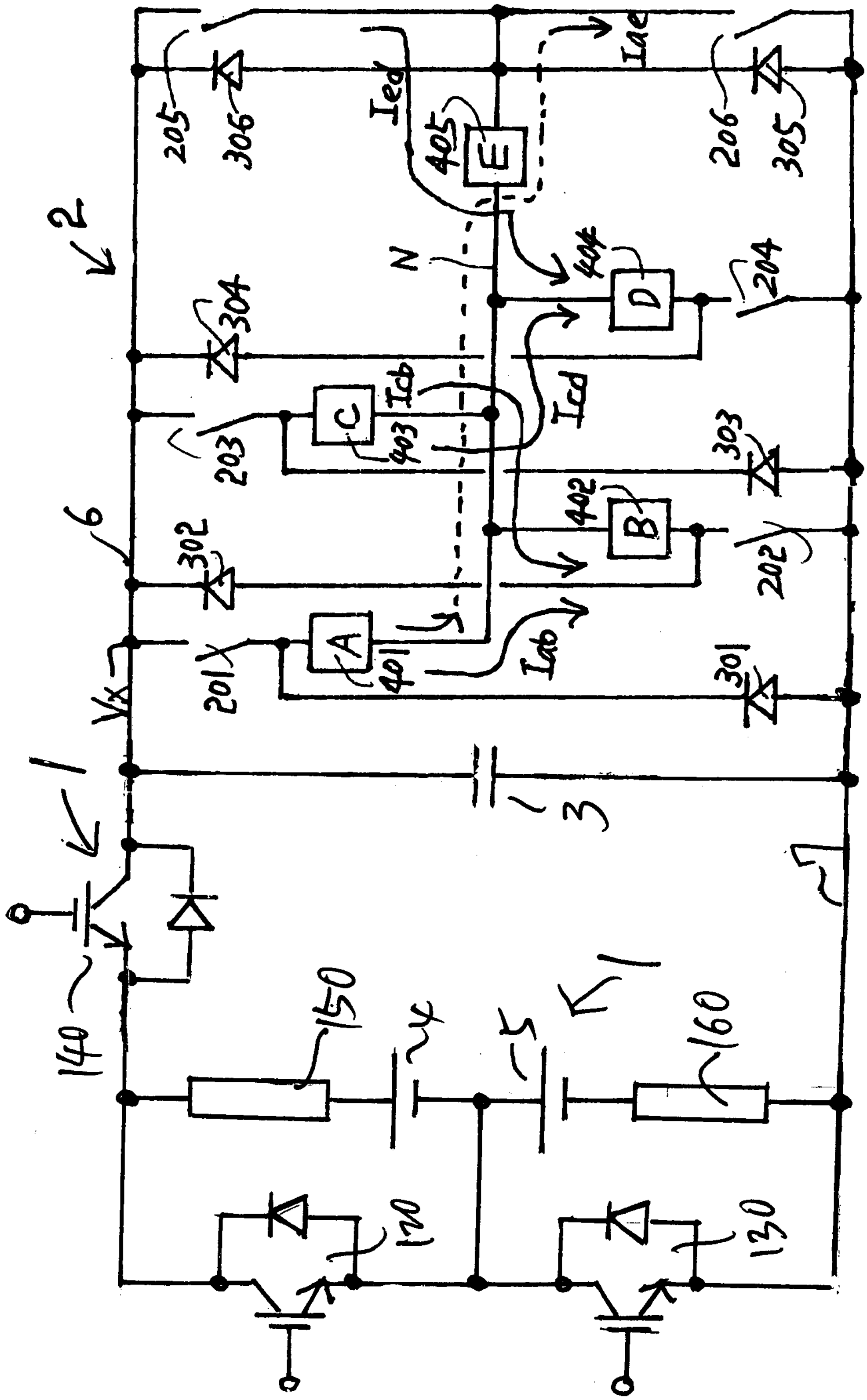
[Fig. 18]


VA
high
Low
t →
0
VB
0
VX
0
I120
0
I130
time → 0
0

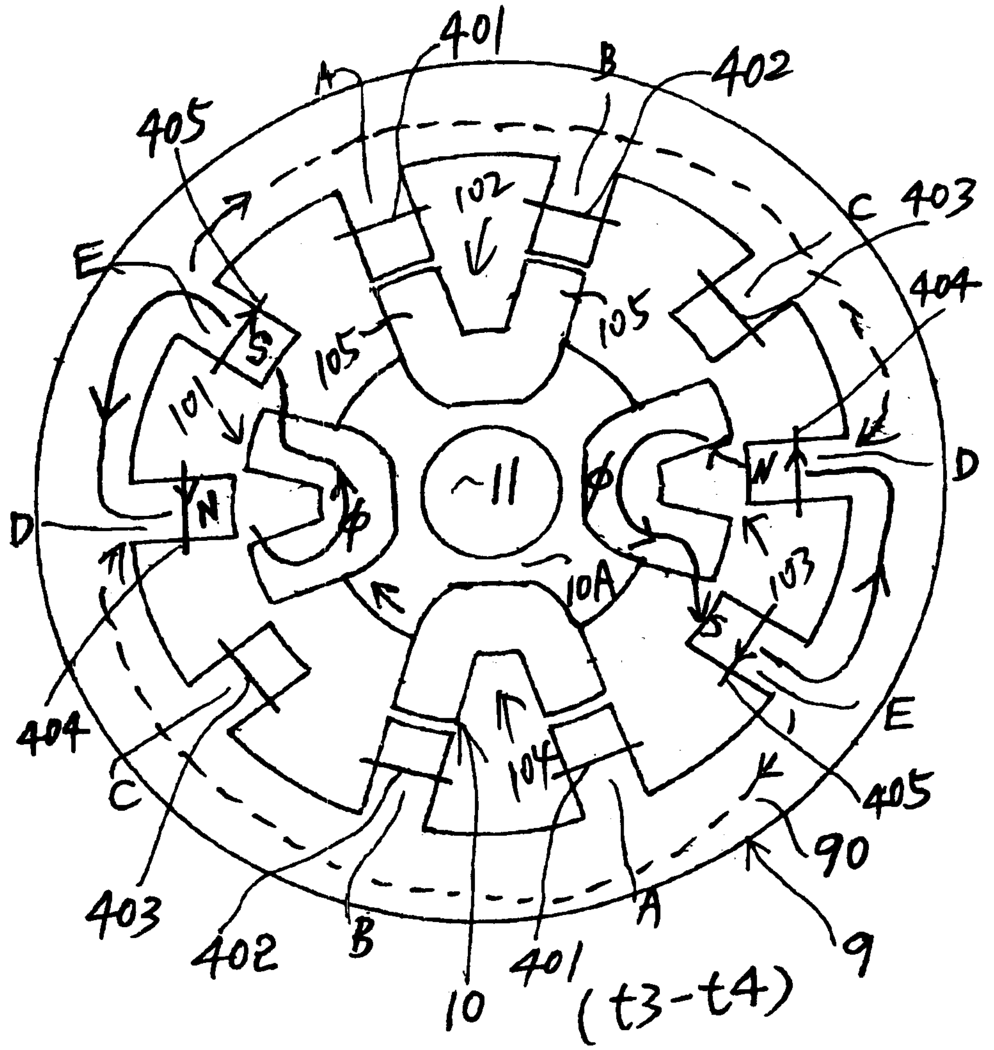
[Fig. 19]


VA
high
Low
t →
0
VB
0
VX
0
I120
I130
time →
0

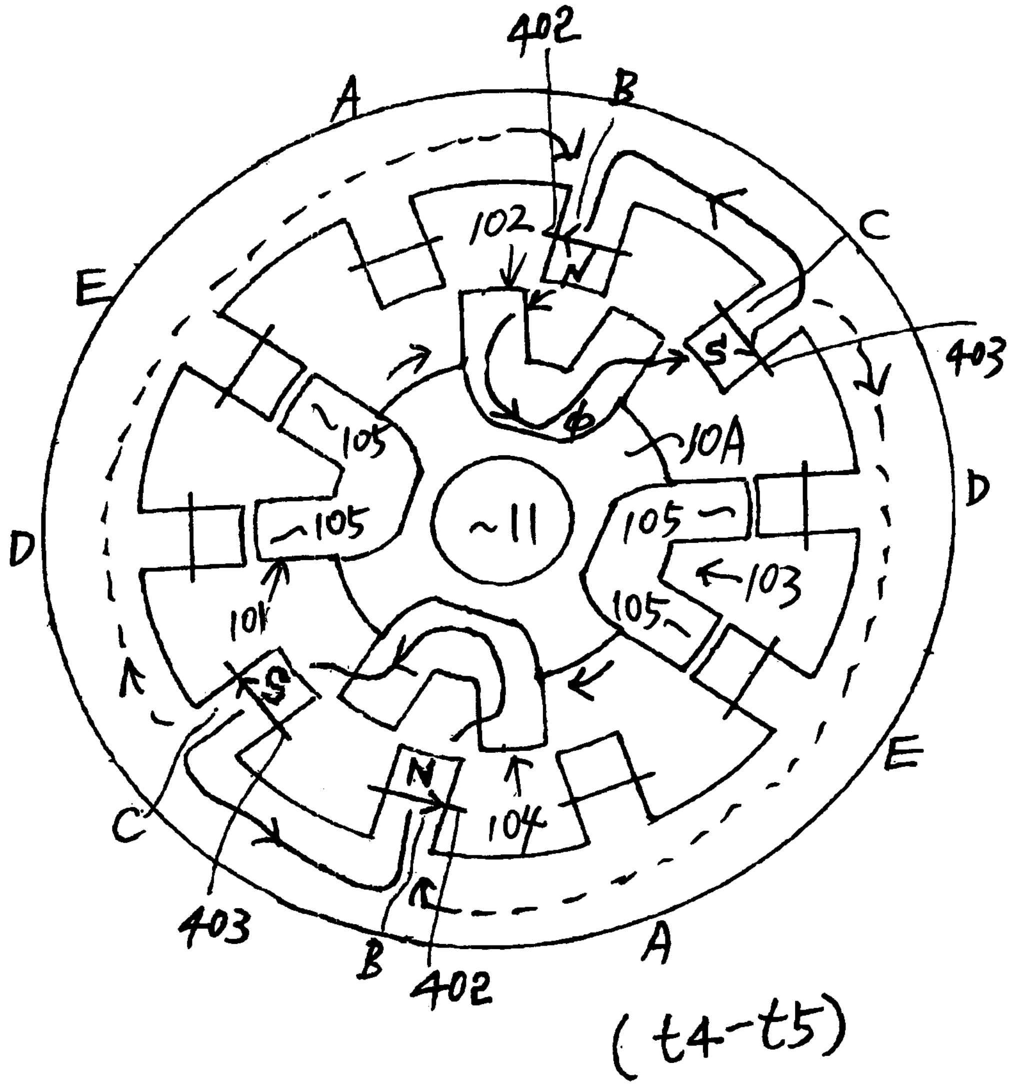
[Fig. 20]


2
205
306
Iea
405
E
Iae
206
305
N
404
D
204
304
C
203
403
Icb
Icd
303
6
302
402
B
202
A
201
401
Iab
301
Vx
1
3
140
150
4
5
160
170
130

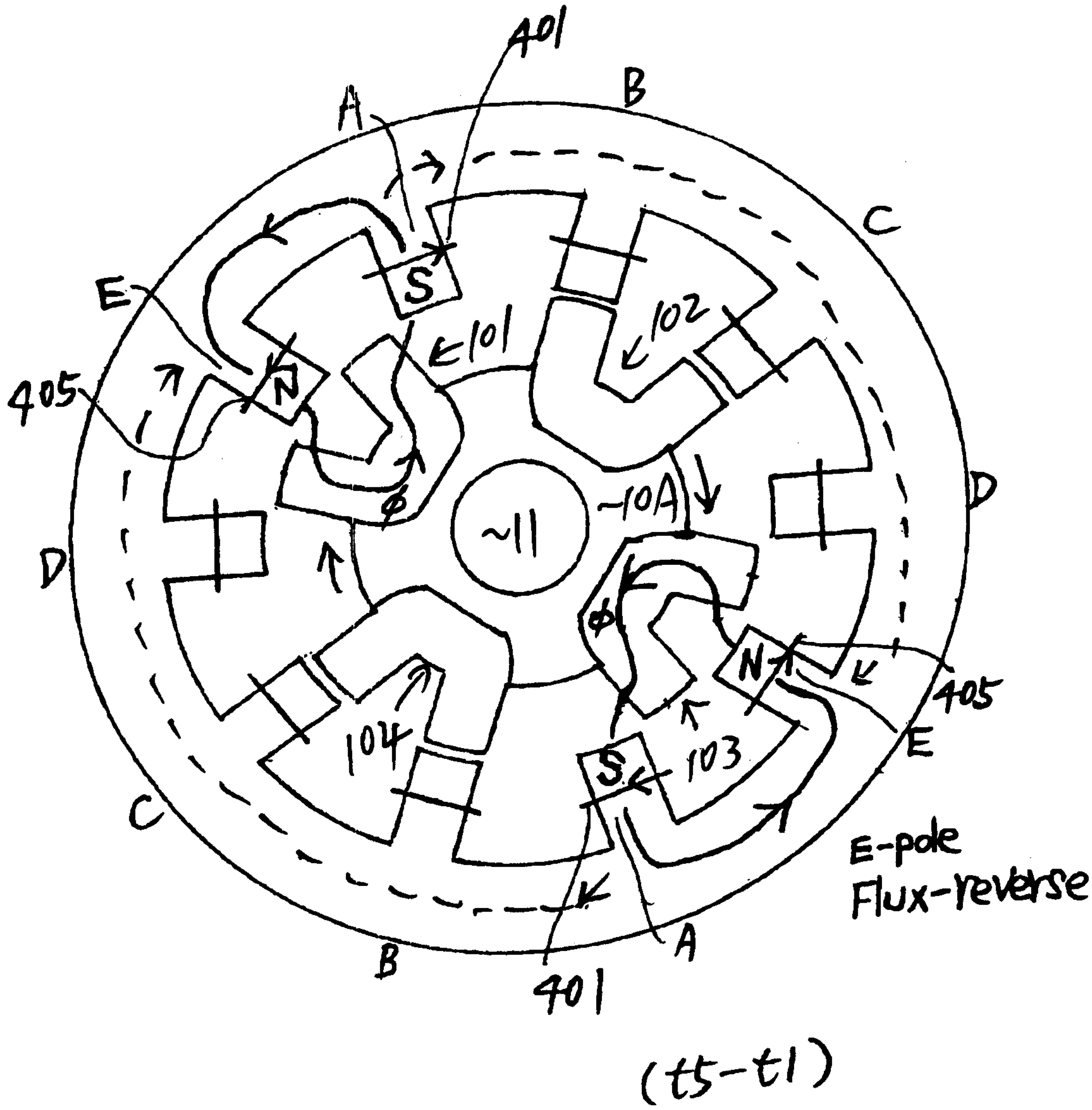
[Fig. 21]


401
A
B
402
405
102
C
403
E
105
105
105
404
S
101
N
D
~11
N
D
φ
φ
10A
103
S
E
404
104
405
C
90
403
402
B
A
401
9
10
(t3-t4)

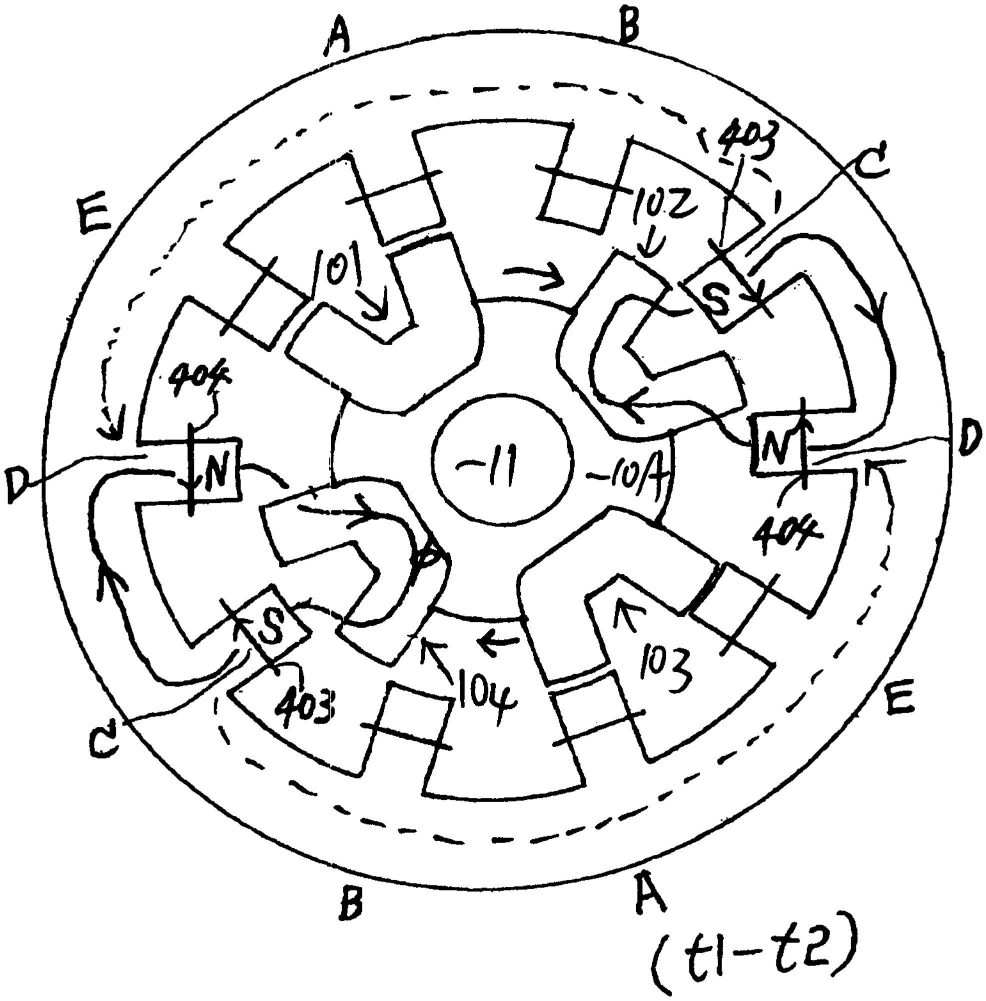
[Fig. 22]


402
A
B
102
C
E
N
S
403
105
105
10A
D
D
11
105
105
103
101
S
N
E
104
C
403
B
402
A
(t4-t5)

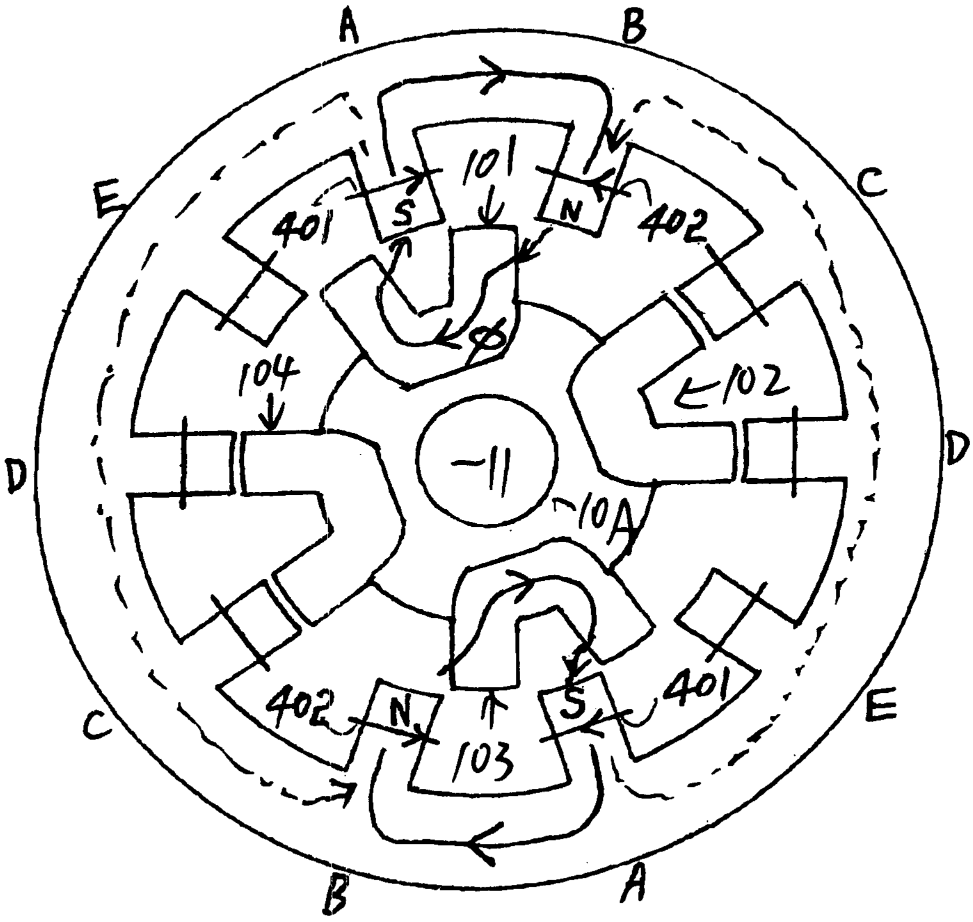
[Fig. 23]


401
A
B
C
E
S
N
101
102
405
~10A
~11
D
φ
104
103
401
A
B
C
E-pole
Flux-reverse
(t5-t1)

[Fig. 24]

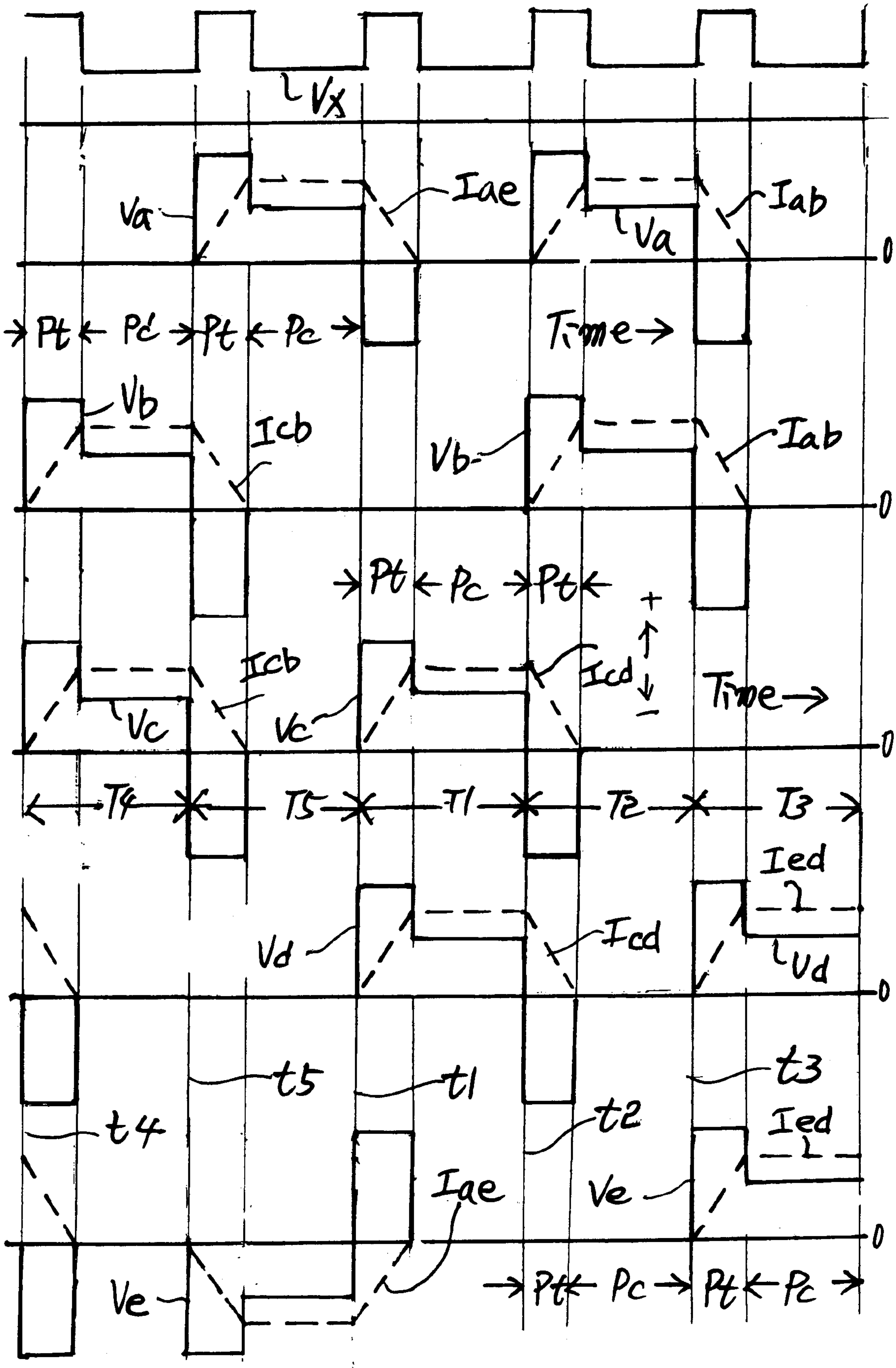


[Fig. 25]

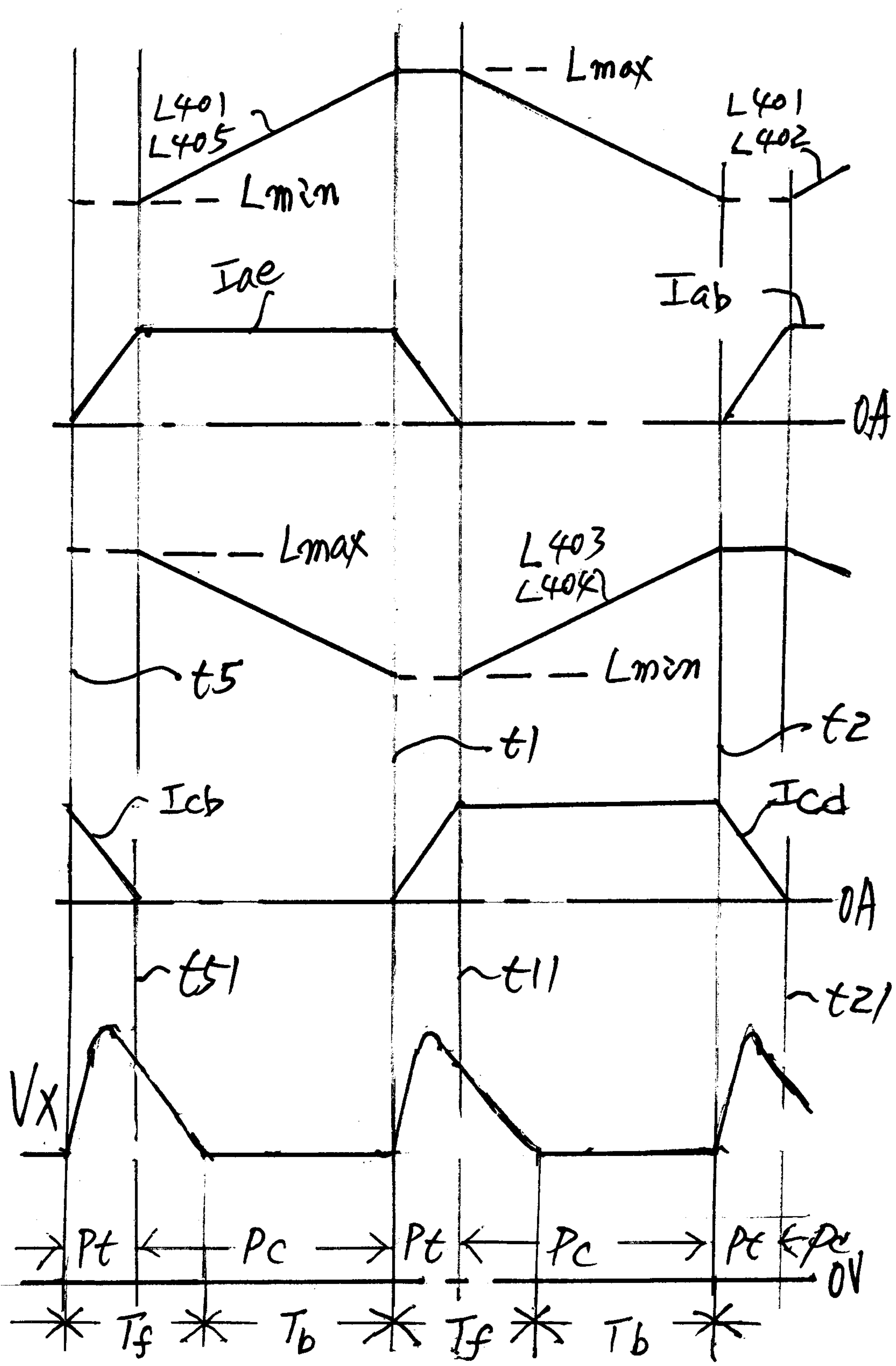


(t2-t3)

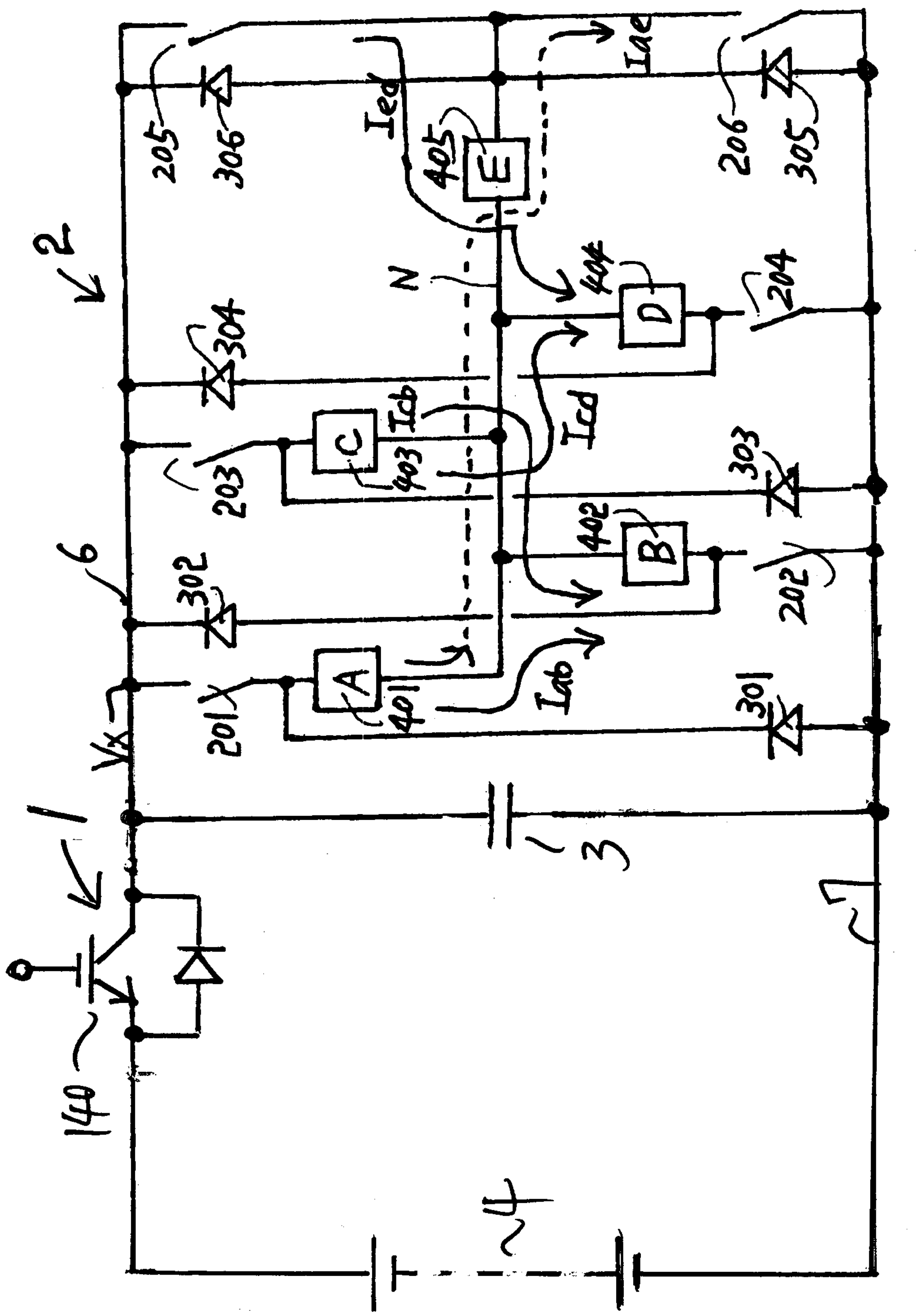
[Fig. 26]


Vx
Va
Iae
Va
Iab
0
Pt
Pc
Pt
Pc
Time
Vb
Icb
Vb
Iab
0
Pt
Pc
Pt
+
Icb
Vc
Vc
Icd
-
Time
0
T4
T5
T1
T2
T3
Ied
Vd
Icd
Vd
0
t5
t1
t3
t4
t2
Ied
Iae
Ve
0
Ve
Pt
Pc
Pt
Pc

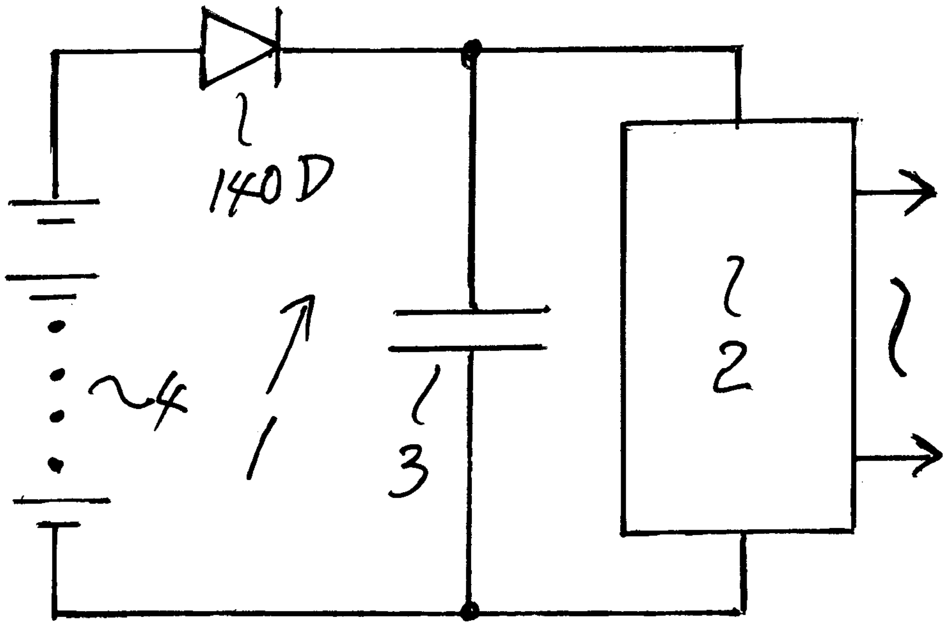
[Fig. 27]


Lmax
L401
L405
Lmin
L401
L402
Iae
Iab
0A
Lmax
L403
L404
Lmin
t5
t1
t2
Icb
Icd
0A
t51
t11
t21
Vx
Pt
Pc
Pt
Pc
Pt
Pc
0V
Tf
Tb
Tf
Tb

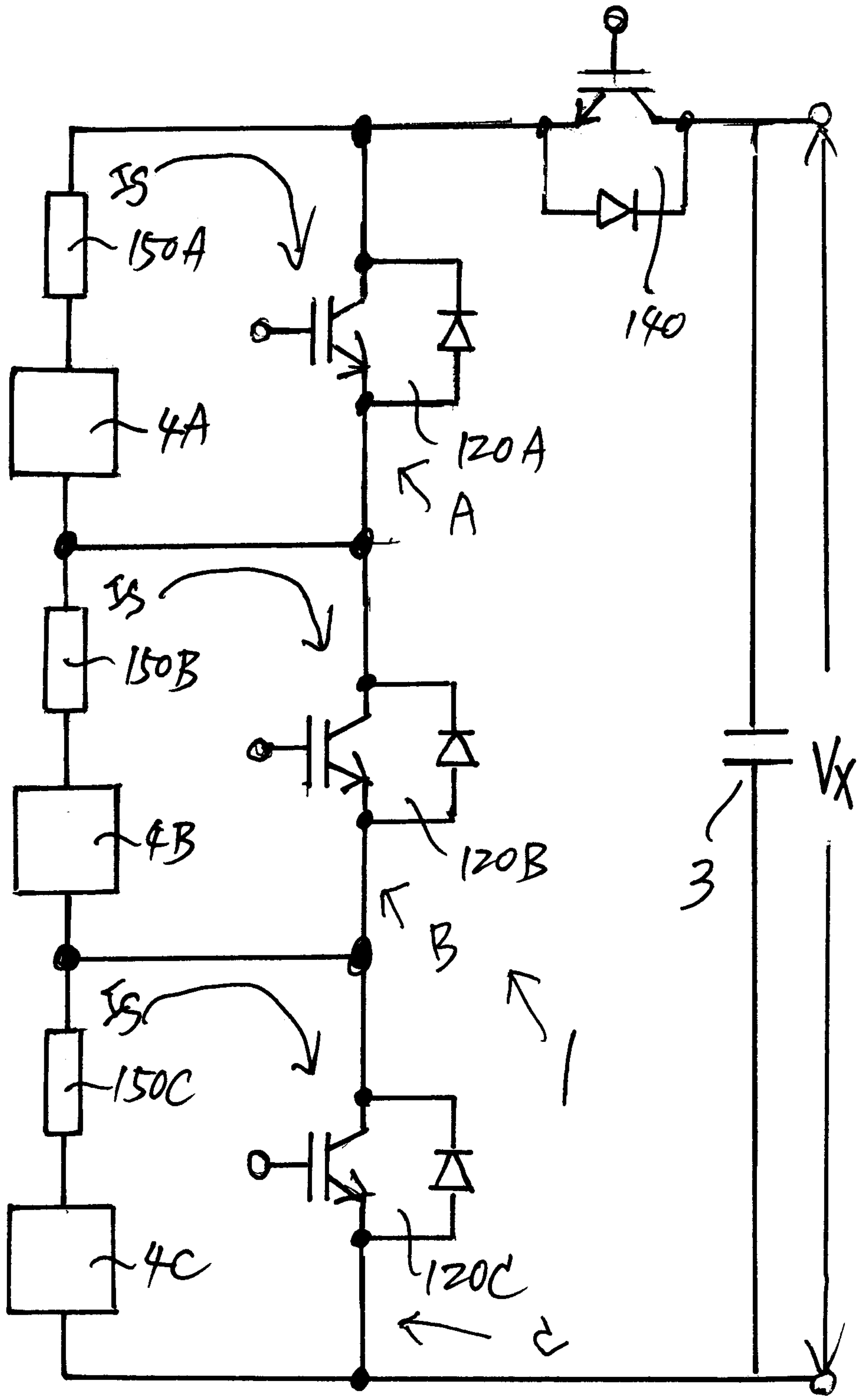
[Fig. 28]


2
6
1
140
3
4
7
Vx
N
A
B
C
D
E
201
202
203
204
205
206
301
302
303
304
305
306
401
402
403
404
405
Iab
Icb
Icd
Ied
Iae

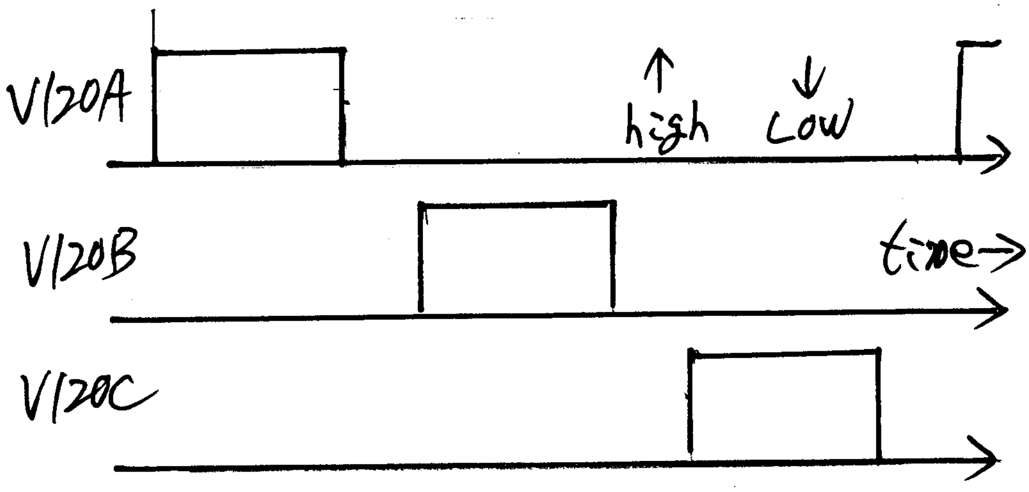
[Fig. 29]



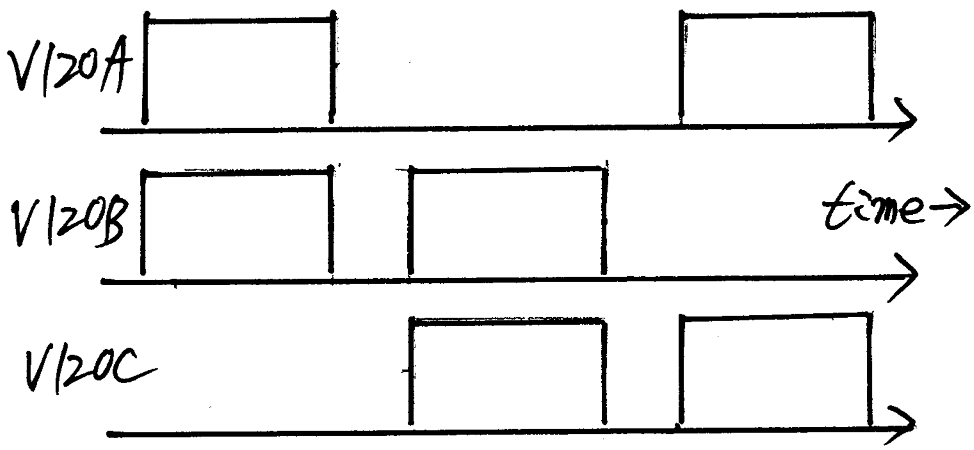
[Fig. 30]



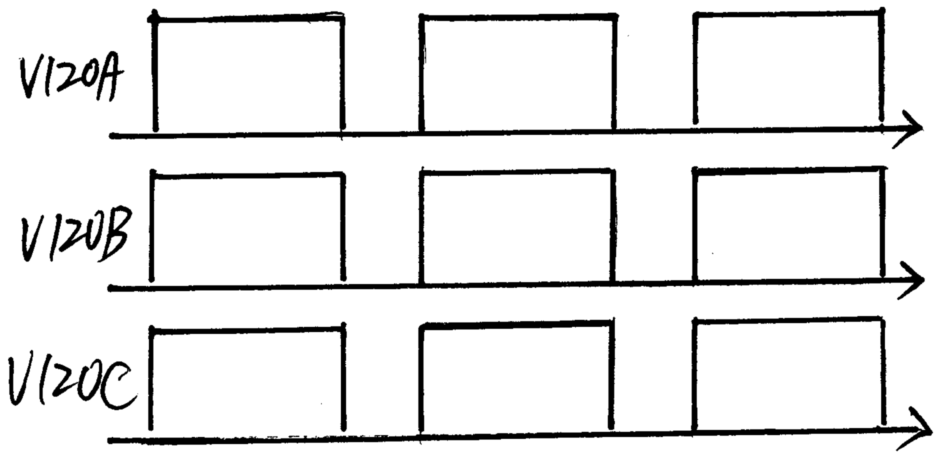
[Fig. 31]



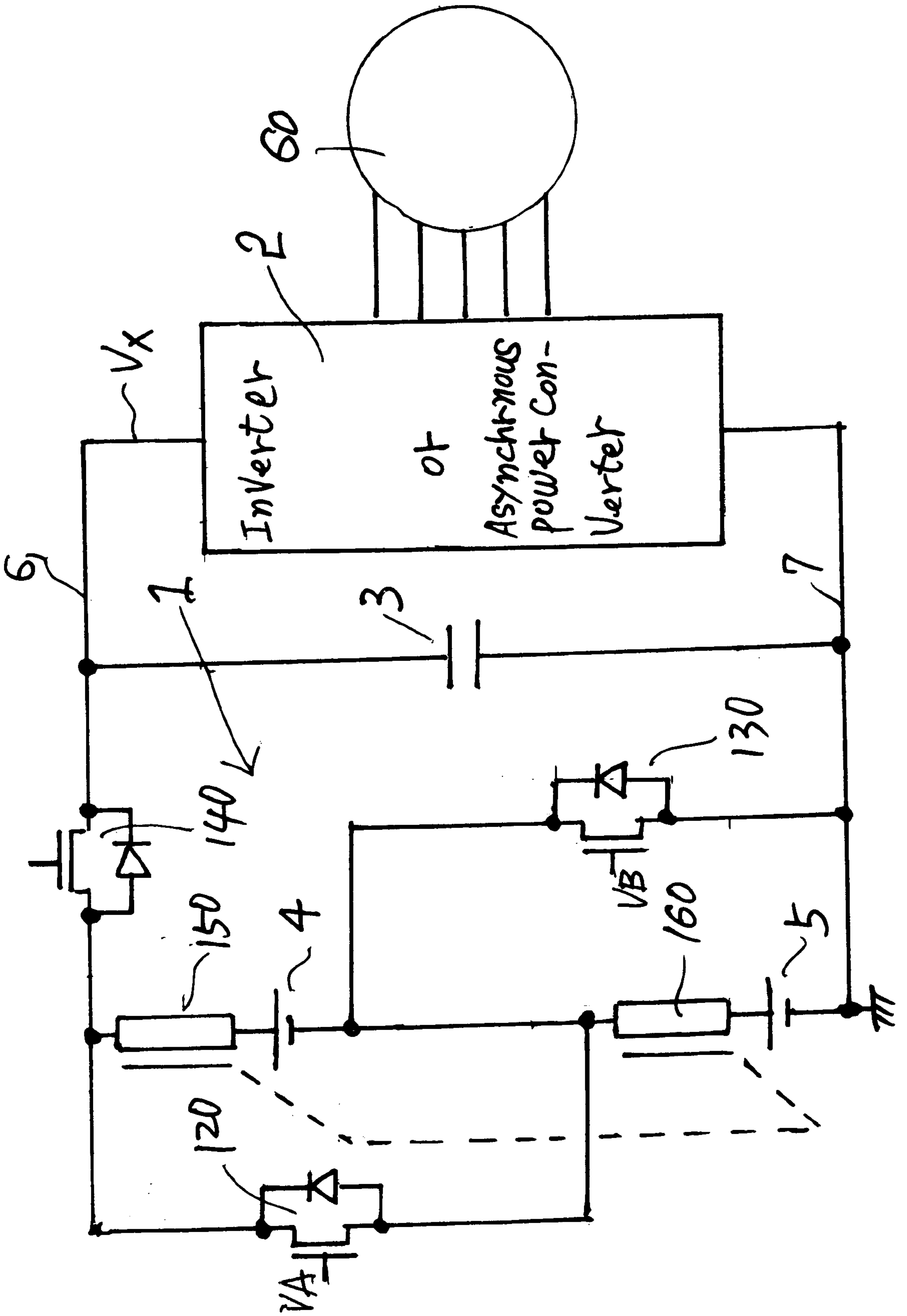
[Fig. 32]



[Fig. 33]



[Fig. 34]


60
2
Inverter
or
Asynchronous
power Con-
verter
Vx
6
1
3
7
130
140
VB
150
4
160
5
120
VA

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2011/002259

A. CLASSIFICATION OF SUBJECT MATTER

Int.Cl. H02M3/155(2006.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

Int.Cl. H02M3/155

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Published examined utility model applications of Japan 1922-1996
Published unexamined utility model applications of Japan 1971-2011
Registered utility model specifications of Japan 1996-2011
Published registered utility model applications of Japan 1994-2011

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y A	JP 2008-5625 A (Toyota Motor Corporation) 2008.01.10, Fig.1-5 & US 2009/0066277 A1	1-2 8-9 3-7
Y	JP 11-113283 A (Toshiba Corp.) 1999.04.23, [0044] & US 6060859 A	8-9
A	JP 2010-193700 A (THREE EYE CO., LTD.) 2010.09.02, all pages non family	1-9

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
03.06.2011	14.06.2011

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