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(54) **An electrical power supply suitable in particular for dc plasma processing**

Eine elektrische Stromversorgung, die besonders für Gleichstromplasmabehandlung anwendbar ist

Une alimentation de puissance électrique, utilisable en particulier pour le traitement de plasma à courant continu

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- **AYYANAR R ET AL: "AN IMPROVED FULL-ZVS-RANGE HYBRID DC-DC CONVERTER WITH LOW FILTER REQUIREMENT CAPABLE OF ADDING AND SUBTRACTING THE CONTROLLED AND UNCONTROLLED SECTIONS" 31ST.ANNUAL IEEE POWER ELECTRONICS SPECIALISTS CONFERENCE. PESC 00. CONFERENCE PROCEEDINGS. GALWAY, IRELAND, JUNE 18 - 23, 2000, ANNUAL POWER ELECTRONICS SPECIALISTS CONFERENCE, NEW YORK, NY: IEEE, US, vol. 1 OF 3. CONF. 31, 18 June 2000 (2000-06-18), pages 179-184, XP000987909 ISBN: 0-7803-5693-4**
- **AYYNAR R ET AL: "A NOVEL SOFT-SWITCHING DC-DC CONVERTER WITH SIDE ZVS-RANGE AND REDUCED FILTER REQUIREMENT" 30TH ANNUAL IEEE POWER ELECTRONICS SPECIALISTS CONFERENCE. PESC 99. RECORD. CHARLESTON,, ANNUAL POWER ELECTRONICS SPECIALISTS CONFERENCE, NEW YORK, NY: IEEE, US, vol. 1, 1999, pages 433-438, XP000924765 ISBN: 0-7803-5422-2**

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Description

Field of the Invention

[0001] The invention concerns a power supply and in particular a power supply suitable for DC and pulsed DC plasma processing.

Background of the invention

[0002] A conventional power supply has the structure shown by Fig. 13 and comprises a H-bridge switching circuit 51, a transformer 52, a rectifier 54 and a filter formed by an inductor 55 and a capacitor 56. Fig. 18 shows a typical output characteristic of such a conventional power supply. As can be appreciated from Fig. 18 such an output characteristic is not suitable for applications in which the electrical load connected to the power supply varies in a broad range, like e.g. in the case of DC plasma processing where the electrical load represented by the plasma does indeed vary in a broad range. Fig. 18 shows that if the electrical load represented by the plasma requires a lower voltage and a higher current, the current capability of a conventional power supply of the type shown by Fig. 13 is relatively limited.

[0003] Prior art power supplies for DC plasma processing follow two different approaches in order to enhance the range of DC current delivered to the electrical load represented by the plasma and to obtain an output characteristic of the type represented by Fig. 19.

[0004] In a first prior art approach illustrated by Figures 14 and 15, the power supply has e.g. the basic structure shown by Fig. 14 which only differs from the conventional power supply shown by Fig. 13 in that a transformer 53 having a primary winding 531 and several secondary windings, e.g. two secondary windings 532, 533, is used instead of transformer 52 in Fig. 13.

[0005] Secondary windings 532, 533 can be connected either in parallel for having a low voltage and a high current capability in the case of a DC plasma processing where a low voltage is required, or in series for having a high voltage and a low current capability in the case of a DC plasma processing where a high voltage is required.

[0006] In order to increase the voltage range of the power supply shown by Fig. 14 it is necessary to change the connection of the secondary windings 532, 533 from their connection in parallel according to Fig. 14 to their connection in series according to Fig. 15. Manual change of this connection is time consuming and therefore undesirable in an ongoing DC plasma processing.

[0007] If the DC plasma processing requires to have two or more plasma types it is necessary to have two or more preconfigured power supplies in order to reduce time loss during the process. The first prior art approach is thus expensive.

[0008] In a second prior art approach illustrated by Figures 16 and 17, the power supply has a similar structure as in Figures 14 and 15, but comprises in addition switch-

es 61, 62, 63 which make it possible to change the connection of the secondary windings 532, 533 from their connection in parallel according to Fig. 16 to their connection in series according to Fig. 17. This second prior art approach has the disadvantage that switches 61, 62, 63 can only be actuated in stand-by mode (not under electrical power) and cannot be actuated during an ongoing plasma processing, because actuation of these switches under electrical power would cause electrical arcs involving the contacts of the switches and would eventually burn these switches. Therefore, this second prior art approach also requires interruption of an ongoing DC plasma processing in order to change the configuration of the connections of the secondary windings 532, 533 in order to modify the output characteristic of the power supply.

[0009] A power supply as defined by the preamble of claim 1 is disclosed in the paper presented at the 31st Annual IEEE Power Electronics Specialists Conference, Pesc 00, Conference Proceedings, Galway, Ireland, June 18-23, 2000, Annual Power Electronics specialists Conference, New York, IEEE, Vol. 1 of 3, 2000, pages 179-184.

[0010] A power supply as defined by the preamble of claim 4 is disclosed in the paper presented at the 30th Annual IEEE Power Electronics Specialists Conference, Pesc 99, Record, Charleston, Annual Power Electronics Specialists Conference, New York, IEEE, Vol. 1, 1999, pages 433-438.

Summary of the Invention

[0011] A main aim of the instant invention is to provide a power supply and in particular a power supply suitable for DC plasma processing.

[0012] A further aim of the invention is to provide a power supply which is able to provide a constant electrical power to an electrical load which varies within a broad range without having to change the hardware configuration of the power supply or to use different arrangements of power supplies for different ranges of electrical power, voltage and current to be applied to such an electrical load.

[0013] A further aim of the invention is to provide a power supply which is in particular able to provide a desired constant electrical power for any value of the variable voltage across the electrical load represented by a plasma.

[0014] According to the invention the above aim is achieved with a power supply defined by claims 1 or 4. Preferred embodiments of a power supply according to the invention are defined by claims 2, 3 and 5 to 16.

[0015] A power supply according to the invention is apt to provide a constant electrical power to an electrical load which for a given voltage varies within a broad range in a ratio of 1 to 10 or more, e.g. the electrical load represented by a plasma. Thus for a given voltage, a power supply according to the invention is apt to satisfy a cor-

responding variation of the current to be supplied to such an electrical load.

[0016] Moreover, a power supply according to the invention is in particular apt to provide a desired constant electrical power for any value of the variable voltage across a plasma.

Brief Description of the Drawings

[0017] The subject invention will now be described in terms of its preferred embodiments. These embodiments are set forth to aid the understanding of the invention, but are not to be construed as limiting.

Fig. 1 shows a first embodiment of a power supply according to the invention,

Fig. 2 shows a circuit of a primary DC source shown in Fig. 1,

Fig. 3 shows in particular control pulses used for controlling the switching elements of bridges 13 and 15 of switching elements shown in Fig. 1 for a first mode of operation,

Fig. 4 shows in particular control pulses used for controlling the switching elements of bridges 13 and 15 of switching elements shown in Fig. 1 for a second mode of operation,

Fig. 5 shows a second embodiment of a power supply according to the invention,

Fig. 6 shows in particular control pulses used for controlling the switching elements of half bridges 23a and 23b of switching elements shown in Fig. 5 for a first mode of operation,

Fig. 7 shows in particular control pulses used for controlling the switching elements of half bridges 23a and 23b of switching elements shown in Fig. 5 for a second mode of operation,

Fig. 8 shows a third embodiment of a power supply according to the invention,

Fig. 9 shows a fourth embodiment of a power supply according to the invention,

Fig. 10 shows a fifth embodiment of a power supply according to the invention,

Fig. 11 shows a sixth embodiment of a power supply according to the invention,

Fig. 12 shows a seventh embodiment of a power supply according to the invention,

Fig. 13 shows the structure of a conventional power supply,

Fig. 14 shows a first connection of secondary windings according to a first prior art approach for enhancing the capabilities of a conventional power supply,

Fig. 15 shows a second connection of secondary windings according to the first prior art approach illustrated by Fig. 14,

Fig. 16 shows a first connection of secondary windings according to a second prior art approach for enhancing the capabilities of a conventional power supply,

Fig. 17 shows a second connection of secondary windings according to a second prior art approach for enhancing the capabilities of a conventional power supply,

Fig. 18 shows a typical U-I output characteristic of a conventional power supply of the type shown by Fig. 13,

Fig. 19 shows a typical U-I output characteristic of a power supply according to a first prior art approach represented in Figures 14 and 15, or according to a second prior art approach represented in Figures 16 and 17,

Fig. 20 shows a typical U-I output characteristic of a power supply according to the invention.

Detailed Description of the Invention

FIRST EMBODIMENT

[0018] This embodiment is described with reference to Figures 1 to 4.

[0019] Figure 1 shows the basic structure of a power supply according to the invention.

[0020] As can be appreciated from Fig. 1 this power supply is a DC-DC converter which comprises two transformers 11 and 22 having each one primary and one secondary winding, a 6-diode-bridge rectifier 16 and control means 17 for providing suitable control pulses which make possible a specified control sequence of two H-bridge switching circuits which thereby connect those transformers to a primary DC source 14 of electrical energy during selected time intervals. Fig. 2 shows a typical structure of primary DC source 14. Primary DC source 14 provides a voltage U_1 .

[0021] Primary DC source 14 receives AC electrical energy through power lines 24, 25, 26, comprises e.g. a 6-diode bridge rectifier circuit, and a filter formed by an inductor 28 and a capacitor 29.

[0022] As can be appreciated from Fig. 1, this embodiment comprises a filtering inductor 18 connected in series with one of the terminal outputs of the bridge rectifier 16.

[0023] As will become apparent from the following description the DC-DC converter shown in Fig. 1 makes possible

- to establish a parallel connection or a serial connection of the energy sources represented by the outputs of the transformers 11 and 12 during predetermined time intervals, and
- to effect a smooth and practically continuous transition from the parallel connection to the serial connection or vice versa.

[0024] These effects obtained with the DC-DC converter shown in Fig. 1 give the power supply according to the invention the capability of providing a constant electrical power to an electrical load, e.g. a plasma, the impedance of which varies within a relatively broad range. This can be appreciated from Fig. 20 which shows a typical U-I output characteristic of a power supply according to the invention.

[0025] The DC-DC converter of the power supply shown in Fig. 1 comprises:

- a first transformer 11 and a second transformer 12,
- a first H-bridge switching circuit 13 comprising switching elements 131, 132, 133, 134,
- a second H-bridge switching circuit 15 comprising switching elements 151, 152, 153, 154,
- a bridge rectifier circuit 16, and
- a control circuit 17.

[0026] Each of the switching elements 131, 132, 133, 134, 151, 152, 153, 154, and switching elements 231, 232, 233, 234 mentioned below with reference to Fig. 5 is e.g. an IGBT or a MOSFET and is connected in parallel with a diode as shown in the accompanying drawings.

[0027] First transformer 11 has a primary winding 111 and a secondary winding 112. The primary winding and the secondary winding of first transformer 11 have the same winding polarity.

[0028] Second transformer 12 has a primary winding 121 and a secondary winding 122. The primary winding and the secondary winding of the second transformer 12 have opposite winding polarities.

[0029] The secondary winding 112 of first transformer 11 has a terminal which is a first transformer output terminal 91.

[0030] Another terminal of secondary winding 112 of first transformer 11 and a terminal of secondary winding 122 of second transformer 12 are connected with each

other at a node which is a second transformer output terminal 92.

[0031] The secondary winding of the second transformer 12 has a terminal which is a third transformer output terminal 93.

[0032] The first H-bridge switching circuit 13 serves for selectively connecting the output of the primary DC source 14 to the primary winding 111 of the first transformer 11. The first H-bridge switching circuit 13 has a leading leg comprising switching elements 131, 132 and a lagging leg comprising switching elements 133, 134.

[0033] The second H-bridge switching circuit 15 serves for selectively connecting the output of the primary DC source to the primary winding of the second transformer. The second H-bridge switching circuit 15 has a leading leg comprising switching elements 151, 152 and a lagging leg comprising switching elements 153, 154.

[0034] The bridge rectifier circuit 16 is a 6-diode-bridge rectifier circuit having the configuration shown by Fig. 1. Bridge rectifier circuit 16 has a first input terminal 101 connected to the first transformer output terminal 91, a second input terminal 102 connected to the second transformer output terminal 92, a third input terminal 103 connected to the third transformer output terminal 93, and output terminals 161, 162 adapted to provide electrical energy to an electrical load 32, optionally via a filter formed e.g. by an inductor 18 and a capacitor 19, and a so called "arc control" circuit 31 which is designed to prevent the formation of electrical arcs during a DC plasma processing. Within the scope of the present description "arc control" circuit 31 is a known circuit and is therefore not described in detail.

[0035] Control circuit 17 is adapted to provide the following control pulses:

- a first set of control pulses, e.g. pulses 131a and 132a in Fig. 3 for effecting switching of switching elements 131, 132 of the leading leg of the first H-bridge switching circuit 13,
- a second set of control pulses, e.g. pulses 133a and 134a in Fig. 3 for effecting switching of switching elements 133, 134 of the lagging leg of the first H-bridge switching circuit 13, this second set of control pulses having an adjustable first phase delay, e.g. phase delay DELTA-1 (δ_1 shown in Fig. 3) with respect to the first set of control pulses,
- a third set of control pulses, e.g. pulses 151a, 152a in Fig. 3 for effecting switching of switching elements 151, 152 of the leading leg of the second H-bridge switching circuit 15, this third set of control pulses having an adjustable second phase delay, e.g. (phase delay ALPHA-1, α_1 shown in Fig. 3) with respect to the first set of control pulses 131a, 132a,
- a fourth set of control pulses, e.g. pulses 153a, 154a

in Fig. 3 for effecting switching of switching elements 153, 154 of the lagging leg of the second H-bridge switching circuit 15, this fourth set of control pulses having an adjustable third phase delay with respect to the third set of control pulses.

[0036] In a preferred embodiment, this third phase delay is equal to the first phase delay, e.g. phase delay DELTA-1.

[0037] In a preferred embodiment, the control pulses of all above mentioned sets of control pulses have all one and the same predetermined duration.

[0038] Two different modes of operation of the above described first embodiment, a first mode of operation called parallel mode and a second mode of operation called parallel/serial mode, are described hereinafter.

[0039] As can be appreciated from the following description, a smooth and practically continuous transition from the first mode into the second mode of operation is attainable by suitable selection and adjustment of the phases of the control pulses used to control the switching elements of the H-bridge switching circuits, the selection and adjustment being effected by means of the control circuit which provides the control pulses. The phases of the control pulses are adjusted e.g. by means of a so called pulse width modulation (PWM).

8.1.1. First mode of operation of the first embodiment (parallel mode)

[0040] Fig. 3 shows a representation of the control pulses used to control the switching elements of the first and second H-bridge switching circuits 13, 15 shown in Fig. 1, as well as a schematic representation of the corresponding waveforms of primary winding voltages U_{p1} of first transformer 11 and U_{p2} second transformer 12.

[0041] The leading leg of the first H-bridge switching circuit comprises two switching elements 131, 132.

[0042] A first set of control pulses 131a, 132a switch switching elements 131, 132 ON and OFF alternately with a duty cycle of about 50% (if a safety dead time between them is disregarded).

[0043] The lagging leg of the first H-bridge switching circuit 13 comprises two switching elements 133, 134. A second set of control pulses 133a, 134a switch switching elements 133, 134 ON and OFF alternately also with a duty cycle of about 50% (if a safety dead time between them is disregarded).

[0044] As can be appreciated from Fig. 3, the second set of control pulses 133a, 134a has a phase delay DELTA-1 (phase delay δ_1 shown in the drawings) with respect to the first set of control pulses 131a, 132a.

[0045] The above described switching of the switching elements of the first H-bridge switching circuit provides a voltage U_{p1} across the primary winding 111 of first transformer 11. Voltage U_{p1} has a waveform which is schematically represented in Fig. 3.

[0046] The leading leg of the second H-bridge 15 switching circuit comprises two switching elements 151, 152. A third set of control pulses 151a, 152a switch switching elements 151, 152 ON and OFF alternately with a duty cycle of about 50% (if a safety dead time between them is disregarded).

[0047] The lagging leg of the second H-bridge switching circuit comprises two switching elements 153, 154. A fourth set of control pulses 153a, 154a switch switching elements 153, 154 ON and OFF alternately also with a duty cycle of about 50% (if a safety dead time between them is disregarded).

[0048] As can be appreciated from Fig. 3, the third set of control pulses 151a, 152a has a phase delay ALPHA-1 (phase delay α_1 shown in the drawings) with respect to the first set of control pulses 131a, 132a, and the fourth set of control pulses 153a, 154a has a phase delay DELTA-1 (phase delay δ_1 shown in the drawings) with respect to the third set of control pulses 151a, 152a.

[0049] The above described switching of the switching elements of the second H-bridge switching circuit 15 provides a voltage U_{p2} across the primary winding 121 of second transformer 12. Voltage U_{p2} has a waveform which is schematically represented in Fig. 3.

[0050] The secondary windings 112 and 122 of transformers 11 and 12 are connected with each other and with 6-diode-bridge rectifier circuit 16 as shown in Fig. 1.

[0051] The waveform of the output U_2 of bridge rectifier 16 is represented in Fig. 3 under the representation of the waveform of U_{p2} .

[0052] Fig. 3 illustrates the case where DELTA-1 = 45 degrees and ALPHA-1 = 90 degrees. In general for the first mode of operation (parallel mode) the value of DELTA is chosen smaller than 90 degrees and the value of ALPHA is chosen equal to 90 degrees.

[0053] By continuously varying the value of the phase delay DELTA-1, it is possible to obtain a corresponding continuous variation of the average output voltage provided at the output of the bridge rectifier 16.

[0054] The choice of a phase delay ALPHA-1 equal to 90 degrees has for consequence that secondary voltages of transformers 11 and 12 are rectified one after the other and therefore the rectified voltage provided at the output of bridge rectifier 16 has a frequency which is four times the switching frequency of the H-bridge switching circuits 13, 15.

[0055] This provides either a minimization of the ripple of the output current provided by the power supply or a reduction of the size of the filtering inductor used in a conventional power supply for the same amount of electrical power delivered to the load.

[0056] The above described first mode of operation (parallel mode) is suitable when a relatively low output voltage is required.

8.1.2. Second mode of operation of the first embodiment (parallel/serial mode)

[0057] An example of the sets of control pulses used to obtain this mode of operation is shown in Fig. 4 which shows diagrams similar and corresponding to those shown in Fig. 3, but for phase delays DELTA-2 (δ_2 shown in Fig. 4) and ALPHA-2 (α_2 shown in Fig. 4) which differ from the values of the phase delays DELTA-1 and ALPHA-1 respectively shown in Fig. 3.

[0058] In the example illustrated by Fig. 4 DELTA-2 = 135 degrees and ALPHA-2 = 135 degrees. In general for the second mode of operation (parallel/serial mode) the value of DELTA-2 is chosen between 90 and 180 degrees and the value of ALPHA-2 is chosen equal to DELTA-2.

[0059] In Fig. 4 the first set of control pulses is 131b, 132b, the second set of control pulses is 133b, 134b, the third set of control pulses is 151b, 152b, and the fourth set of control pulses is 153b, 154b.

[0060] Fig. 4 also shows a schematic representation of the waveforms of primary winding voltages U_{p1} and U_{p2} of the first and the second transformer 11, 12 respectively, for the case in which the phase delays are DELTA-2 = 135 degrees and ALPHA-2 = 135 degrees.

[0061] With this second mode of operation it is also possible to obtain a continuous variation of the average output voltage provided at the output of the bridge rectifier by effecting a corresponding continuous variation of the value of the phase delay DELTA-2 and of the phase delay ALPHA-2 = DELTA-2 and the average voltage obtainable at the output of the bridge rectifier is higher than for the first mode of operation and reaches a maximum of twice the voltage provided by a secondary winding of one of the transformers 11, 12 when DELTA is equal to 180 degrees.

[0062] As can be appreciated from the example represented by Fig. 4, when phase delay ALPHA-2 delay is equal to phase delay DELTA-2 and is greater than 90 degrees the electrical energy sources represented by the secondary windings of the transformers 11 and 12 are in parallel during predetermined time intervals and in series during other predetermined time intervals.

[0063] As can be appreciated from Fig. 1, the secondary winding 122 of the second transformer 12 is of opposite polarity with respect to the primary winding 121 of the second transformer 12, and the primary and secondary windings of the first transformer 11 have the same polarity. Due to this arrangement, the voltages across the secondary windings of the first and second transformers 11, 12 have opposite polarity and the corresponding rectified voltages add together during predetermined time intervals. Due to this, the output voltage of the bridge rectifier will be the double of one of the voltages across a secondary winding of one of the transformers 11, 12 during those intervals.

[0064] The ripple frequency is twice the switching frequency of the H-bridge switching circuits. The magnitude of the square voltage is twice lower than in the case of a

conventional power supply. The ripple is lower than the ripple obtained with a conventional power supply having the same output filter.

[0065] The above described second mode of operation (parallel/serial mode) is suitable when a higher output voltage is required than the one obtainable with the first mode of operation.

8.1.3. Continuous transition from the first mode into the second mode of operation

[0066] As can be appreciated from the foregoing description, a smooth and practically continuous transition from the first mode into the second mode of operation is attainable by suitable selection and adjustment of the phases of the control pulses used to control the switching elements of the H-bridge switching circuits, the selection and adjustment being effected by means of the control circuit 17 which provides the control pulses.

SECOND EMBODIMENT

[0067] This embodiment is described with reference to Figures 5 to 7.

[0068] Fig. 5 schematically shows the basic structure of this second embodiment which is a variant of the basic circuit structure of the first embodiment represented in Fig. 1.

[0069] The embodiment shown by Fig. 5 comprises two half bridge switching circuits 23a and 23b and a primary winding terminal of each of transformers 11 and 12 is connected to a node which is a middle point of a capacitive voltage divider formed by capacitors 33 and 34. The output voltage obtained with this configuration is only half the value of the output voltage obtained with configuration with two H-bridge switching circuits of the type shown by Fig. 1.

[0070] The two half bridge switching circuits 23a and 23b serve for selectively connecting primary DC source 14 to the primary winding of the first transformer 11 and to the primary winding of the second transformer 12. Half bridge switching circuit 23a constitutes a first leg which includes switching elements 231 and 232 and half bridge switching circuit 23b constitutes a second leg which includes switching elements 231 and 232.

[0071] A circuit formed by a series connection of a first capacitor 33 and a second capacitor 34 is connected in parallel with the first leg 231, 232 and with the second leg 233, 234, and that circuit has a node to which a terminal of capacitor 33 and a terminal of capacitor 34 are connected to. The latter node is connected to a terminal of each of the primary windings of transformers 11 and 12.

[0072] The embodiment shown by Fig. 5 comprises a bridge rectifier circuit 16 of the same type described above with reference to Fig. 1 and a control circuit 17 which provides sets of control pulses shown in Figures 6 and 7.

[0073] Control circuit provides e.g. the following sets of control pulses shown e.g. in Fig. 6:

- a first set of control pulses 231a, 232a for effecting switching of switching elements 231, 232 of the first leg formed by half bridge switching circuit 23a, each of the control pulses of the first set having an adjustable duration,
- a second set of control pulses 233a, 234a for effecting switching of switching elements 233, 234 of the second leg formed by half bridge switching circuit 23b, each of the control pulses of the second set having an adjustable duration,

[0074] In a preferred embodiment the adjustable duration of each of the control pulses of the second set of control pulses is equal to the adjustable duration of each of the control pulses of the first set of control pulses.

[0075] The control of the switching elements shown in Fig. 5 is to some extent similar to the control of the switching elements shown in Fig. 1.

[0076] Fig 6 shows the sets of control pulses for the parallel mode of the embodiment shown by Fig. 5 with a control pulse duration $\text{TAU-1} = 45$ degrees ($\tau_1 = 45$ degrees).

[0077] In Fig. 6 the first set of control pulses is 231a, 232a and the second set of control pulses is 233a, 234a. The second set of control pulses 233a, 234a has a predetermined phase delay DELTA-3 (δ_3 in Fig. 6), with respect to the first set of control pulses 231a, 232a.

[0078] Fig 7 shows the sets of control pulses for the parallel/serial mode of this embodiment with a control pulse duration $\text{TAU-2} = 135$ degrees ($\tau_2 = 135$ degrees).

[0079] In Fig. 7 the first set of control pulses is 231b, 232b and the second set of control pulses is 233b, 234b. The second set of control pulses 233b, 234b has a predetermined phase delay DELTA-4 (δ_4 in Fig. 7), with respect to the first set of control pulses 231b, 232b.

[0080] In a preferred embodiment when TAU-1 is smaller than 90 degrees, then DELTA-3 is chosen equal to 90 degrees, and when TAU-2 is greater than 90 degrees, then DELTA-4 is chosen equal to TAU-2 .

THIRD EMBODIMENT

[0081] This embodiment is described with reference to Fig. 8.

[0082] Fig. 8 shows an example of a combination of a plurality of DC-DC converters having the basic structure described above with reference to Figures 1 to 4 or of a plurality of DC-DC converters having the basic structure described above with reference to Figures 5 to 7 in order to build a power supply having enhanced power supply capabilities, e.g. a higher range of output voltage and/or output current, and having the above mentioned inherent advantages of those basic structures. For this purpose one or more basic structures according to Fig. 1 or to Fig.

5 are combined as shown by Fig. 8. The combined structure can thus comprise 2, 4, 6 and in general $2N$ transformers.

FOURTH EMBODIMENT

[0083] This embodiment is described with reference to Fig. 9.

[0084] This embodiment has to a large part the basic structure described above with reference to Fig. 1, but differs therefrom in that it comprises two 4-diode bridge rectifiers 35, 36 instead of the 6-diode bridge rectifier 16 shown by Fig. 1.

[0085] Bridge rectifier circuit 35 includes four diodes and has

a first input terminal 101 connected to the first transformer output terminal 91, and

a second input terminal 102 connected to the second transformer output terminal 92.

[0086] Bridge rectifier circuit 36 includes four diodes and has

a first input terminal 103 connected to the second transformer output terminal 92, and

a second input terminal 104 connected to the third transformer output terminal 93.

[0087] The combined bridge rectifier circuit 35-36 has output terminals 361, 362.

FIFTH EMBODIMENT

[0088] This embodiment is described with reference to Fig. 10.

[0089] Fig. 10 shows an example of a combination of a plurality of DC-DC converters having the basic structure described above with reference to Fig. 9 in order to build a power supply having enhanced power supply capabilities, e.g. a higher range of output voltage and/or output current, and having the above mentioned inherent advantages of those basic structures. For this purpose one or more structures comprising each a transformer and a four-diode bridge rectifier are combined with the basic structure represented in Fig. 9 as shown by Fig. 10. The combined structure can thus comprise 2, 3, 4, and in general N transformers, the minimum number being 2 transformers.

SIXTH EMBODIMENT

[0090] This embodiment is described with reference to Fig. 11.

[0091] Fig. 11 shows a sixth embodiment which is a variant of the basic circuit structure of the first embodiment represented in Fig. 1 and differs therefrom in that it comprises an additional inductor 113, 123 (typical value

50 microhenry) connected in series with each of the primary windings 111, 121 of transformers 11 and 22, and a capacitor connected in parallel with each of the switching elements. In Fig. 11 these capacitors are designated with reference numbers 41 to 48. A typical value for each of these capacitors is 2 to 4 nanofarad.

[0092] Inductors 113, 123 shown in Fig. 11 are used to achieve a so called Zero Voltage Switching (ZVS)

[0093] The current flowing through inductors 113, 123 (so called ZVS inductors) needs some time to pass from the positive to the negative direction and vice versa.

[0094] Specially during the switching OFF of the leading leg of a H-bridge, the current flowing through the inductance 18 will flow through the rectifier bridge 16 that will free wheel and short circuit the secondary winding of the transformer and thereby also the primary of the transformer, and due to this effect a very long time is needed for resetting the current flowing through a ZVS inductor. This time requirement causes a loss in duty cycle capability and therefore a loss in output voltage capability. These phenomena do not allow the obtention of twice the output voltage across the secondary winding when the above mentioned the phase delay DELTA is equal to 180 degrees (loss in duty cycle capability).

[0095] As can be appreciated from Fig. 11, this embodiment also comprises a filtering inductor 11 connected in series with one of the terminal outputs of bridge rectifier 16.

SEVENTH EMBODIMENT

[0096] This embodiment is described with reference to Fig. 12.

[0097] Fig. 12 schematically shows a seventh embodiment which is a variant of the circuit structure of the sixth embodiment represented in Fig. 11 and differs therefrom in that

- each of the additional inductors L1 which are connected in series with each of the primary windings of transformers 11 and 12 is replaced by a leakage inductance 114, 124 (typical value 50 microhenry) of the primary winding of the transformer 11 respectively 12, and the filtering inductor 18 connected to the output of bridge rectifier 16 is eliminated, that is the output of the bridge rectifier is connected directly to an output capacitor 39 as shown by Fig. 12.

[0098] Removal of the filtering inductor 18 and connection of the output capacitor 39 (typical value 0.5 microfarad) directly across the output of bridge rectifier 16 has two effects. A first effect is that the leakage inductance 114 (124), now the ZVS inductance, of the transformer is used not only for the purpose of ZVS, but also for the performing the filtering of the output signal provided by the power supply. A second effect is that the voltage on capacitor 39 across the output of bridge rec-

tifier 16 is the output voltage, that this voltage corresponds to the transformer secondary voltage and therefore also corresponds to the voltage across the primary winding of the transformer, then the primary winding is not anymore short-circuited. Therefore, eventually the re-setting of the ZVS inductance current will be very short and therefore the loss in duty cycle capability is substantially reduced.

10 List of reference numbers

[0099]

11	transformer
12	transformer
13	H-bridge switching circuit
14	primary DC source
15	H-bridge switching circuit
16	bridge rectifier circuit
17	control circuit
18	inductor
19	capacitor
20	transformer
21	transformer
22	transformer
23a	half bridge switching circuit
23b	half bridge switching circuit
24	power line
25	power line
26	power line
27	bridge rectifier circuit
28	inductor
29	capacitor
30	"arc control" circuit
31	electrical load
32	capacitor
33	capacitor
34	bridge rectifier circuit
35	bridge rectifier circuit
36	capacitor
37	capacitor
38	capacitor
39	capacitor
40	capacitor
41	capacitor
42	capacitor
43	capacitor
44	capacitor
45	capacitor
46	capacitor
47	capacitor
48	capacitor
49	H-bridge switching circuit
50	transformer
51	transformer
52	rectifier
53	inductor
54	capacitor
55	transformer output terminal
56	transformer output terminal
57	transformer output terminal
58	transformer output terminal
59	transformer output terminal
60	transformer output terminal
91	transformer output terminal
92	transformer output terminal
93	transformer output terminal

100	101	input terminal of bridge rectifier	
102		input terminal of bridge rectifier	
103		input terminal of bridge rectifier	
104		input terminal of bridge rectifier	
111		primary winding	
112		secondary winding	
113		inductor	
114		leakage inductance of transformer 11 seen from its primary winding	
121		primary winding	
122		secondary winding	
123		inductor	
124		leakage inductance of transformer 12 seen from its primary winding	
131		switching element	
132		switching element	
133		switching element	
134		switching element	
151		switching element	
152		switching element	
153		switching element	
154		switching element	
161		output terminal	
162		output terminal	
231		switching element	
232		switching element	
233		switching element	
234		switching element	
361		output terminal	
362		output terminal	
531		primary winding	
532		secondary winding	
533		secondary winding	
U ₁		DC output voltage of primary DC source 14	
U ₂		unfiltered output voltage of bridge rectifier 16	
U ₃		filtered output voltage of bridge rectifier 16	
U ₄		output voltage of "arc control" circuit	
n		transformer ratio	
I ₂		output current of bridge rectifier	
I ₃		output current of DC-DC converter	
I ₄		output current of "arc control" circuit	
δ		DELTA, phase delay	
α		ALPHA, phase delay	
τ		TAU, duration expressed as a fraction of a period of 360 degrees	

[0100] Although a preferred embodiment of the invention has been described using specific terms, such de-

scription is for illustrative purposes only, and it is to be understood that changes and variations may be made without departing from the scope of the following claims.

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Claims

1. A power supply comprising a DC-DC converter which comprises

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(a) a first transformer (11) having a primary winding (111) and a secondary winding (112), said primary winding and said secondary winding of said first transformer having the same winding polarity;

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(b) a second transformer (12) having a primary winding (121) and a secondary winding (122), said primary winding and said secondary winding of said second transformer having opposite winding polarities;

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said secondary winding of said first transformer (11) having a terminal which is a first transformer output terminal (91), another terminal of said secondary winding of said first transformer (11) and a terminal of said secondary winding of said second transformer (12) being connected with each other at a node which is a second transformer output terminal (92), and said secondary winding of said second transformer (12) having a terminal which is a third transformer output terminal (93);

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(c) a first H-bridge switching circuit (13) for selectively connecting a primary DC source (14) to the primary winding of said first transformer, said first H-bridge switching circuit (13) having a leading leg and a lagging leg, each of these legs including switching elements;

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(d) a second H-bridge (15) switching circuit for selectively connecting said primary DC source (14) to the primary winding of said second transformer (12), said second H-bridge switching circuit (15) having a leading leg and a lagging leg, each of these legs including switching elements; (e) a bridge rectifier circuit (16, 35-36) having a first input terminal connected to the first transformer output terminal (91), and a third input terminal connected to the third transformer output terminal (93);

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(f) a control circuit (17) for providing

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(f.1) a first set of control pulses (131a, 132a) for effecting switching of switching elements (131, 132) of said leading leg of said first H-bridge switching circuit (13),

(f.2) a second set of control pulses (133a,

- 134a) for effecting switching of switching elements (133, 134) of said lagging leg of said first H-bridge switching circuit (13), said second set of control pulses having an adjustable first phase delay with respect to said first set of control pulses, (f.3) a third set of control pulses (151a, 152a) for effecting switching of switching elements (151, 152) of said leading leg of said second H-bridge switching circuit (15), said third set of control pulses having an adjustable second phase delay with respect to said first set of control pulses, (f.4) a fourth set of control pulses (153a, 154a) for effecting switching of switching elements (153, 154) of said lagging leg of said second H-bridge switching circuit (15), said fourth set of control pulses having an adjustable third phase delay with respect to said third set of control pulses, **characterized in that** the bridge rectifier circuit (16, 35-36) has a second input terminal which is connected to the second transformer output terminal (92).
2. A power supply according to claim 1, wherein said third phase delay is equal to said first phase delay.
3. A power supply according to claim 1, wherein said control pulses of all said sets of control pulses have all one and the same predetermined duration.
4. A power supply comprising a DC-DC converter which comprises
- (a) a first transformer (11) having a primary winding and a secondary winding, said primary winding and said secondary winding of said first transformer having the same winding polarity;
- (b) a second transformer (12) having a primary winding and a secondary winding, said primary winding and said secondary winding of said second transformer having opposite winding polarities;
- said secondary winding of said first transformer (11) having a terminal which is a first transformer output terminal, another terminal of said secondary winding of said first transformer (11) and a terminal of said secondary winding of said second transformer (12) being connected with each other at a node which is a second transformer output terminal, and said secondary winding of said second transformer (12) having a terminal which is a third transformer output terminal;
- (c) a first half bridge switching circuit (23a) and a second half bridge switching circuit (23b) for selectively connecting a primary DC source (14) to the primary winding of said first transformer (11) and to the primary winding of said second transformer (12), said first half bridge switching circuit (23a) forming a first leg, said second half bridge switching circuit (23b) forming a second leg, each of these legs including switching elements;
- (d) a circuit formed by a series connection of a first capacitor (33) and a second capacitor (34), said circuit being connected in parallel with said first leg and with said second leg,
- said circuit formed by said series connection of said first capacitor (33) and said second capacitor (34) having another node to which a terminal of each of said first and second capacitors is connected, said another node being connected to the terminal of said primary winding of said first transformer (11) which is not connected to said first half bridge switching circuit,
- (e) a bridge rectifier circuit (16, 35-36) having a first input terminal connected to the first transformer output terminal (91), and a third input terminal connected to the third transformer output terminal (93);
- (f) a control circuit (17) for providing
- (f.1) a first set of control pulses for effecting switching of switching elements of said first leg formed by said first half bridge switching circuit (23a), each of said control pulses of said first set having an adjustable duration,
- (f.2) a second set of control pulses for effecting switching of switching elements of said second leg formed by said second half bridge switching circuit (23b), each of said control pulses of said second set having an adjustable duration,
- said second set of control pulses having a predetermined phase delay with respect to said first set of control pulses, **characterized in that** the bridge rectifier circuit (16, 35-36) has a second input terminal which is connected to the second transformer output terminal and **in that** said another node is connected to the terminal of said primary winding of said second transformer which is not connected to said second half bridge switching circuit.
5. A power supply according to claim 4, wherein said adjustable duration of each of the control pulses of said second set of control pulses is equal to said adjustable duration of each of the control pulses of

said first set of control pulses.

6. A power supply according to any of claims 1 to 5, wherein said bridge rectifier circuit (16) includes six diodes. 5
7. A power supply comprising a combination of a plurality of DC-DC converters of the kind defined in claim 6. 10
8. A power supply according to any of claims 1 to 5, wherein said bridge rectifier circuit (35-36) comprises
 - (i) a first bridge rectifier circuit (35) including four diodes and being
 - connected to said first transformer output terminal and
 - to said second transformer output terminal, 20
 - (ii) a second bridge rectifier circuit (36) including four diodes and being
 - connected to said second transformer output terminal and
 - to said third transformer output terminal, and 25
 - (iii) output terminals (361, 362). 30
9. A power supply comprising a combination of a plurality of DC-DC converters of the kind defined in claim 8. 35
10. A power supply according to any of the preceding claims 1 to 9, further comprising means for performing zero voltage switching of the switching elements of said H-bridge switching circuits (13, 15, 23). 40
11. A power supply according to claim 10, wherein said means for performing zero voltage switching comprise the inductance of a first inductor (113) connected in series with the primary winding of said first transformer (11), the inductance of a second inductor (123) connected in series with the primary winding of said second transformer (12), and capacitors (41 to 48) connected each in parallel with a switching element of the H-bridge switching circuits (13, 15, 23). 45 50
12. A power supply according to claim 11, wherein the leakage inductance (114) of said first transformer (11) is used instead of said first inductor (113) and/or the leakage inductance (124) of said second transformer (12) is used instead of said second inductor (123). 55

13. A power supply according to claim 12, wherein leakage inductances (114, 124) of said first transformer (11) and said second transformer (12) are exclusively used as inductances for performing said zero voltage switching.
14. A power supply according to claim 12, wherein leakage inductances (114, 124) of said first transformer (11) and said second transformer (12) are exclusively used instead of an output filtering inductor (18) which would otherwise be connected in series with an output terminal of said bridge rectifier (16, 35-36).
15. A power supply according to any of claims 11 to 14, wherein said means for performing said zero voltage switching further comprise a capacitor (39) connected across the output terminals of said bridge rectifier (16, 35-36), said capacitor (39) serving for reducing the resetting time of said inductances (113, 114, 123, 124) for performing said zero voltage switching.
16. A power supply according to any of the preceding claims 1 to 15 **characterized in that** it is so configured and dimensioned that it is particularly suitable as a power supply for plasma processing.

Patentansprüche

1. Stromversorgung mit einem DC-DC Wandler mit
 - (a) einem ersten Transformator (11) mit einer Primärwicklung (111) und einer Sekundärwicklung (112), wobei die Primärwicklung und die Sekundärwicklung des ersten Transformators dieselbe Wicklungspolarität aufweisen;
 - (b) einem zweiten Transformator (12) mit einer Primärwicklung (121) und einer Sekundärwicklung (122), wobei die Primärwicklung und die Sekundärwicklung des zweiten Transformators entgegengesetzte Wicklungspolaritäten aufweisen;

wobei die Sekundärwicklung des ersten Transformators (11) einen Anschluss aufweist, der ein erster Transformator-Ausgangsanschluss (91) ist, ein weiterer Anschluss der Sekundärwicklung des ersten Transformators (11) und ein Anschluss der Sekundärwicklung des zweiten Transformators (12) an einem Knoten miteinander verbunden sind, der ein zweiter Transformator-Ausgangsanschluss (92) ist und die Sekundärwicklung des zweiten Transformators (12) einen Anschluss aufweist, der ein dritter Transformator-Ausgangsanschluss (93) ist;

(c) einem ersten H-Brückenschaltkreis (13) zum wahlweisen Verbinden einer primären Gleichstromquelle (14) mit der Primärwicklung des ersten Transformators, wobei der erste H-Brückenschaltkreis (13) einen vorseilenden Zweig und einen nacheilenden Zweig aufweist und jeder dieser Zweige Schaltelemente beinhaltet;

(d) einem zweiten H-Brückenschaltkreis (15) zum wahlweisen Verbinden der primären Gleichstromquelle (14) mit der Primärwicklung des zweiten Transformators (12), wobei der zweite H-Brückenschaltkreis (15) einen vorseilenden Zweig und einen nacheilenden Zweig aufweist und jeder dieser Zweige Schaltelemente beinhaltet;

(e) einer Brückengleichrichterschaltung (16, 35-36), wovon ein erster Eingangsanschluss mit dem ersten Transformator-Ausgangsanschluss (91) verbunden ist und ein dritter Eingangsanschluss mit dem dritten Transformator-Ausgangsanschluss (93) verbunden ist;

(f) einer Steuerschaltung (17) zur Erzeugung

(f.1) einer ersten Gruppe von Steuerimpulsen (131a, 132a) zum Schalten von Schaltelementen (131, 132) des vorseilenden Zweigs des ersten H-Brückenschaltkreises (13),

(f.2) einer zweiten Gruppe von Steuerimpulsen (133a, 134a) zum Schalten von Schaltelementen (133, 134) des nacheilenden Zweigs des ersten H-Brückenschaltkreises (13),

wobei die zweite Gruppe von Steuerimpulsen eine einstellbare erste Phasenverzögerung gegenüber der ersten Gruppe von Steuerimpulsen aufweist,

(f.3) einer dritten Gruppe von Steuerimpulsen (151a, 152a) zum Schalten von Schaltelementen (151, 152) des vorseilenden Zweigs des zweiten H-Brückenschaltkreises (15),

wobei die dritte Gruppe von Steuerimpulsen eine einstellbare zweite Phasenverzögerung gegenüber der ersten Gruppe von Steuerimpulsen aufweist,

(f.4) einer vierten Gruppe von Steuerimpulsen (153a, 154a) zum Schalten von Schaltelementen (153, 154) des nacheilenden Zweigs des zweiten H-Brückenschaltkreises (15),

wobei die vierte Gruppe von Steuerimpulsen eine einstellbare dritte Phasenverzögerung gegenüber der dritten Gruppe von Steuerimpulsen aufweist, **dadurch gekennzeichnet, dass** die Brückengleichrichterschaltung (16, 35-36) einen zweiten Eingangsanschluss aufweist, der mit dem

zweiten Transformator-Ausgangsanschluss (92) verbunden ist.

2. Stromversorgung nach Anspruch 1, wobei die dritte Phasenverzögerung gleich der ersten Phasenverzögerung ist.

3. Stromversorgung nach Anspruch 1, wobei die Steuerimpulse aller der genannten Gruppen von Steuerimpulsen alle ein und dieselbe vorgegebene Dauer aufweisen.

4. Stromversorgung mit einem DC-DC Wandler mit

(a) einem ersten Transformator (11) mit einer Primärwicklung und einer Sekundärwicklung, wobei die Primärwicklung und die Sekundärwicklung des ersten Transformators dieselbe Wicklungspolarität aufweisen;

(b) einem zweiten Transformator (12) mit einer Primärwicklung und einer Sekundärwicklung, wobei die Primärwicklung und die Sekundärwicklung des zweiten Transformators entgegengesetzte Wicklungspolaritäten aufweisen;

wobei die Sekundärwicklung des ersten Transformators (11) einen Anschluss aufweist, der ein erster Transformator-Ausgangsanschluss ist,

ein weiterer Anschluss der Sekundärwicklung des ersten Transformators (11) und ein Anschluss der Sekundärwicklung des zweiten Transformators (12) an einem Knoten miteinander verbunden sind, der ein zweiter Transformator-Ausgangsanschluss ist, und die Sekundärwicklung des zweiten Transformators (12) einen Anschluss aufweist, der ein dritter Transformator-Ausgangsanschluss ist;

(c) einem ersten Halbbrückenschaltkreis (23a) und einem zweiten Halbbrückenschaltkreis (23b) zum wahlweisen Verbinden einer primären Gleichstromquelle (14) mit der Primärwicklung des ersten Transformators (11) und mit der Primärwicklung des zweiten Transformators (12), wobei der erste Halbbrückenschaltkreis (23a) einen ersten Zweig bildet, der zweite Halbbrückenschaltkreis (23b) einen zweiten Zweig bildet und jeder dieser Zweige Schaltelemente beinhaltet;

(d) einer Schaltung gebildet aus einer Serieschaltung eines ersten Kondensators (33) und eines zweiten Kondensators (34), wobei diese Schaltung mit dem ersten Zweig und mit dem zweiten Zweig parallel geschaltet ist,

wobei die Schaltung gebildet aus der Serie-

- schaltung des ersten Kondensators (33) und des zweiten Kondensators (34) einen weiteren Knoten aufweist, mit dem jeweils ein Anschluss des ersten und des zweiten Kondensators verbunden ist, wobei der genannte weitere Knoten mit dem Anschluss der Primärwicklung des ersten Transformators (11) verbunden ist, der nicht mit dem ersten Halbbrückenschaltkreis verbunden ist;
- (e) einer Brückengleichrichterschaltung (16, 35-36), wovon ein erster Eingangsanschluss mit dem ersten Transformator-Ausgangsanschluss (91) verbunden ist und ein dritter Eingangsanschluss mit dem dritten Transformator-Ausgangsanschluss (93) verbunden ist;
- (f) einer Steuerschaltung (17) zur Erzeugung
- (f.1) einer ersten Gruppe von Steuerimpulsen zum Schalten von Schaltelementen des ersten, vom ersten Halbbrückenschaltkreis (23a) gebildeten Zweigs, wobei jeder der Steuerimpulse der genannten ersten Gruppe eine einstellbare Dauer aufweist,
- (f.2) einer zweiten Gruppe von Steuerimpulsen zum Schalten von Schaltelementen des zweiten, vom zweiten Halbbrückenschaltkreis (23b) gebildeten Zweigs, wobei jeder der Steuerimpulse der genannten zweiten Gruppe eine einstellbare Dauer aufweist, wobei die zweite Gruppe von Steuerimpulsen eine vorgegebene Phasenverzögerung gegenüber der ersten Gruppe von Steuerimpulsen aufweist, **dadurch gekennzeichnet, dass** die Brückengleichrichterschaltung (16, 35-36) einen zweiten Eingangsanschluss aufweist, der mit dem zweiten Transformator-Ausgangsanschluss verbunden ist, und dass der genannte weitere Knoten mit dem Anschluss der Primärwicklung des zweiten Transformators verbunden ist, der nicht mit dem zweiten Halbbrückenschaltkreis verbunden ist.
5. Stromversorgung nach Anspruch 4, wobei die einstellbare Dauer jedes Steuerimpulses der genannten zweiten Gruppe von Steuerimpulsen gleich der einstellbaren Dauer jedes Steuerimpulses der genannten ersten Gruppe von Steuerimpulsen ist.
6. Stromversorgung nach einem der Ansprüche 1 bis 5, wobei die Brückengleichrichterschaltung (16) sechs Dioden beinhaltet.
7. Stromversorgung mit einer Kombination einer Mehrzahl von DC-DC Wandlern der in Anspruch 6 definierten Art.
8. Stromversorgung nach einem der Ansprüche 1 bis 5, wobei die Brückengleichrichterschaltung (35-36) beinhaltet:
- (i) eine erste Brückengleichrichterschaltung (35), die vier Dioden umfasst und mit dem ersten Transformator-Ausgangsanschluss und mit dem zweiten Transformator-Ausgangsanschluss verbunden ist,
- (ii) eine zweite Brückengleichrichterschaltung (36), die vier Dioden umfasst und mit dem zweiten Transformator-Ausgangsanschluss und mit dem dritten Transformator-Ausgangsanschluss verbunden ist, und
- (iii) Ausgangsanschlüsse (361, 362).
9. Stromversorgung mit einer Kombination einer Mehrzahl von DC-DC Wandlern der in Anspruch 8 definierten Art.
10. Stromversorgung nach einem der vorstehenden Ansprüche 1 bis 9, weiter enthaltend Mittel für die Nullspannungsschaltung der Schaltelemente der genannten H-Brückenschaltkreise (13, 15, 23).
11. Stromversorgung nach Anspruch 10, wobei die Mittel für die Nullspannungsschaltung die Induktivität einer ersten, mit der Primärwicklung des ersten Transformators (11) in Serie geschalteten Spule (113), die Induktivität einer zweiten, mit der Primärwicklung des zweiten Transformators (12) in Serie geschalteten Spule (123) und mit jeweils einem Schaltelement der H-Brückenschaltkreise (13, 15, 23) parallel geschalteten Kondensatoren (41 bis 48) umfassen.
12. Stromversorgung nach Anspruch 11, wobei anstelle der ersten Spule (113) die Streuinduktivität (114) des ersten Transformators (11) und/oder anstelle der zweiten Spule (123) die Streuinduktivität (124) des zweiten Transformators (12) benutzt wird.
13. Stromversorgung nach Anspruch 12, wobei als Induktivitäten für die Nullspannungsschaltung ausschliesslich Streuinduktivitäten (114, 124) des ersten Transformators (11) und des zweiten Transformators (12) benutzt werden.
14. Stromversorgung nach Anspruch 12, wobei anstelle einer Ausgangsfilterspule (18), die sonst mit einem Ausgangsanschluss des Brückengleichrichters (16, 35-36) in Serie geschaltet wäre, ausschliesslich Streuinduktivitäten (114, 124) des ersten Transformators (11) und des zweiten Transformators (12) benutzt werden.
15. Stromversorgung nach einem der Ansprüche 11 bis 14, wobei die genannten Mittel für die Nullspan-

nungsschaltung weiter einen mit den Ausgangsanschlüssen des Brückengleichrichters (16, 35-36) parallel verbundenen Kondensator (39) umfassen, wobei der Kondensator (39) zur Verkürzung der Rückstellzeit der genannten Induktivitäten (113, 114, 123, 124) für die Nullspannungsschaltung dient.

16. Stromversorgung nach einem der vorstehenden Ansprüche 1 bis 15, **dadurch gekennzeichnet, dass** sie so aufgebaut und dimensioniert ist, dass sie besonders geeignet ist als Stromversorgung für die Plasmabehandlung.

Revendications

1. Unité d'alimentation comprenant un convertisseur continu-continu qui comprend

(a) un premier transformateur (11) ayant un enroulement primaire (111) et un enroulement secondaire (112), ledit enroulement primaire et ledit enroulement secondaire dudit premier transformateur ayant la même polarité d'enroulement;

(b) un deuxième transformateur (12) ayant un enroulement primaire (121) et un enroulement secondaire (122), ledit enroulement primaire et ledit enroulement secondaire dudit deuxième transformateur ayant des polarités d'enroulement opposées;

ledit enroulement secondaire dudit premier transformateur (11) ayant une borne qui est une première borne de sortie de transformateur (91),

une autre borne dudit enroulement secondaire dudit premier transformateur (11) et une borne dudit enroulement secondaire dudit deuxième transformateur (12) étant reliées l'une à l'autre en un noeud qui est une deuxième borne de sortie de transformateur (92), et

ledit enroulement secondaire dudit deuxième transformateur (12) ayant une borne qui est une troisième borne de sortie de transformateur (93);

(c) un premier circuit de commutation à pont en H (13) pour relier sélectivement une source primaire de courant continu (14) à l'enroulement primaire dudit premier transformateur, ledit premier circuit de commutation à pont en H (13) ayant une branche en avant et une branche en arrière, chacune de ces branches incluant des éléments de commutation;

(d) un deuxième circuit de commutation à pont

en H (15) pour relier sélectivement ladite source de courant continu (14) à l'enroulement primaire dudit deuxième transformateur (12), ledit deuxième circuit de commutation à pont en H (15) ayant une branche en avant et une branche en arrière, chacune de ces branches incluant des éléments de commutation;

(e) un circuit redresseur en pont (16, 35-36) dont une première borne d'entrée est reliée à la première borne de sortie de transformateur (91) et une troisième borne d'entrée est reliée à la troisième borne de sortie de transformateur (93);

(f) un circuit de commande (17) pour fournir

(f.1) un premier ensemble d'impulsions de commande (131a, 132a) pour effectuer la commutation d'éléments de commutation (131, 132) de ladite branche en avant dudit premier circuit de commutation à pont en H (13),

(f.2) un deuxième ensemble d'impulsions de commande (133a, 134a) pour effectuer la commutation d'éléments de commutation (133, 134) de ladite branche en arrière dudit premier circuit de commutation à pont en H (13),

ledit deuxième ensemble d'impulsions de commande ayant un premier décalage de phase réglable par rapport audit premier ensemble d'impulsions de commande,

(f.3) un troisième ensemble d'impulsions de commande (151a, 152a) pour effectuer la commutation d'éléments de commutation (151, 152) de ladite branche en avant dudit deuxième circuit de commutation à pont en H (15),

ledit troisième ensemble d'impulsions de commande ayant un deuxième décalage de phase réglable par rapport audit premier ensemble d'impulsions de commande,

(f.4) un quatrième ensemble d'impulsions de commande (153a, 154a) pour effectuer la commutation d'éléments de commutation (153, 154) de ladite branche en arrière dudit deuxième circuit de commutation à pont en H (15),

ledit quatrième ensemble d'impulsions de commande ayant un troisième décalage de phase réglable par rapport audit troisième ensemble d'impulsions de commande, **caractérisée en ce que** le circuit redresseur en pont (16, 35-36) a une deuxième borne d'entrée qui est reliée à la deuxième borne de sortie de transformateur (92).

2. Unité d'alimentation selon la revendication 1, où ledit troisième décalage de phase est égal audit premier décalage de phase.

3. Unité d'alimentation selon la revendication 1, où lesdites impulsions de commande de tous lesdits ensembles d'impulsions de commande ont toutes une même durée prédéterminée.

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4. Unité d'alimentation comprenant un convertisseur continu-continu qui comprend

(a) un premier transformateur (11) ayant un enroulement primaire et un enroulement secondaire, ledit enroulement primaire et ledit enroulement secondaire dudit premier transformateur ayant la même polarité d'enroulement;

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(b) un deuxième transformateur (12) ayant un enroulement primaire et un enroulement secondaire, ledit enroulement primaire et ledit enroulement secondaire dudit deuxième transformateur ayant des polarités d'enroulement opposées;

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ledit enroulement secondaire dudit premier transformateur (11) ayant une borne qui est une première borne de sortie de transformateur,

une autre borne dudit enroulement secondaire dudit premier transformateur (11) et une borne dudit enroulement secondaire dudit deuxième transformateur (12) étant reliées l'une à l'autre en un noeud qui est une deuxième borne de sortie de transformateur, et

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ledit enroulement secondaire dudit deuxième transformateur (12) ayant une borne qui est une troisième borne de sortie de transformateur;

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(c) un premier circuit de commutation en demi-pont (23a) et un deuxième circuit de commutation en demi-pont (23b) pour relier sélectivement une source primaire de courant continu (14) à l'enroulement primaire dudit premier transformateur (11) et à l'enroulement primaire dudit deuxième transformateur (12), ledit premier circuit de commutation en demi-pont (23a) formant une première branche, ledit deuxième circuit de commutation en demi-pont (23b) formant une deuxième branche, chacune de ces branches incluant des éléments de commutation;

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(d) un circuit constitué d'un montage en série d'un premier condensateur (33) et d'un deuxième condensateur (34), ledit circuit étant monté en parallèle avec ladite première branche et avec ladite deuxième branche,

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ledit circuit constitué dudit montage en série dudit premier condensateur (33) et dudit deuxième condensateur (34) ayant un autre

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noeud auquel est reliée une borne de chacun desdits premier et deuxième condensateurs,

ledit autre noeud étant relié à la borne dudit enroulement primaire dudit premier transformateur (11) qui n'est pas reliée audit premier circuit de commutation en demi-pont;

(e) un circuit redresseur en pont (16, 35-36) dont une première borne d'entrée est reliée à la première borne de sortie de transformateur (91) et une troisième borne d'entrée est reliée à la troisième borne de sortie de transformateur (93);

(f) un circuit de commande (17) pour fournir

(f.1) un premier ensemble d'impulsions de commande pour effectuer la commutation d'éléments de commutation de ladite première branche formée par ledit premier circuit de commutation en demi-pont (23a), chacune desdites impulsions de commande dudit premier ensemble ayant une durée réglable,

(f.2) un deuxième ensemble d'impulsions de commande pour effectuer la commutation d'éléments de commutation de ladite deuxième branche formée par ledit deuxième circuit de commutation en demi-pont (23b), chacune desdites impulsions de commande dudit deuxième ensemble ayant une durée réglable, ledit deuxième ensemble d'impulsions de commande ayant un décalage de phase prédéterminé par rapport audit premier ensemble d'impulsions de commande, **caractérisée en ce que** le circuit redresseur en pont (16, 35-36) a une deuxième borne d'entrée qui est reliée à la deuxième borne de sortie de transformateur et que ledit autre noeud est relié à la borne dudit enroulement primaire dudit deuxième transformateur qui n'est pas reliée audit deuxième circuit de commutation en demi-pont.

5. Unité d'alimentation selon la revendication 4, où ladite durée réglable de chacune des impulsions de commande dudit deuxième ensemble d'impulsions de commande est égale à ladite durée réglable de chacune des impulsions de commande dudit premier ensemble d'impulsions de commande.

6. Unité d'alimentation selon l'une quelconque des revendications 1 à 5, où ledit circuit redresseur en pont (16) comprend six diodes.

7. Unité d'alimentation comprenant une combinaison d'une pluralité de convertisseurs continu-continu du genre défini à la revendication 6.

8. Unité d'alimentation selon l'une quelconque des revendications 1 à 5, où ledit circuit redresseur en pont (35-36) comprend
- (i) un premier circuit redresseur en pont (35) comprenant quatre diodes et étant relié à ladite première borne de sortie de transformateur et à ladite deuxième borne de sortie de transformateur, 5
 - (ii) un deuxième circuit redresseur en pont (36) comprenant quatre diodes et étant relié à ladite deuxième borne de sortie de transformateur et à ladite troisième borne de sortie de transformateur, et 10
 - (iii) des bornes de sortie (361, 362). 15
9. Unité d'alimentation comprenant une combinaison d'une pluralité de convertisseurs continu-continu du genre défini à la revendication 8. 20
10. Unité d'alimentation selon l'une quelconque des revendications 1 à 9, comprenant en outre des moyens pour effectuer la commutation à tension nulle des éléments de commutation desdits circuits de commutation à pont en H (13, 15, 23). 25
11. Unité d'alimentation selon la revendication 10, où lesdits moyens pour effectuer la commutation à tension nulle comprennent l'inductance d'une première bobine d'induction (113) montée en série avec l'enroulement primaire dudit premier transformateur (11), l'inductance d'une deuxième bobine d'induction (123) montée en série avec l'enroulement primaire dudit deuxième transformateur (12) et des condensateurs (41 à 48) chacun montés en parallèle avec un élément de commutation des circuits de commutation à pont en H (13, 15, 23). 30 35
12. Unité d'alimentation selon la revendication 11, où l'inductance de fuite (114) dudit premier transformateur (11) est utilisée au lieu de ladite première bobine d'induction (113) et/ou l'inductance de fuite (124) dudit deuxième transformateur (12) est utilisée au lieu de ladite deuxième bobine d'induction (123). 40 45
13. Unité d'alimentation selon la revendication 12, où des inductances de fuite (114, 124) dudit premier transformateur (11) et dudit deuxième transformateur (12) sont exclusivement utilisées en tant qu'inductances pour effectuer ladite commutation à tension nulle. 50
14. Unité d'alimentation selon la revendication 12, où des inductances de fuite (114, 124) dudit premier transformateur (11) et dudit deuxième transformateur (12) sont exclusivement utilisées au lieu d'une bobine d'induction de filtrage de sortie (18) qui serait autrement montée en série avec une borne de sortie 55

dudit redresseur en pont (16, 35-36).

15. Unité d'alimentation selon l'une quelconque des revendications 11 à 14, où lesdits moyens pour effectuer ladite commutation à tension nulle comprennent en outre un condensateur (39) relié aux bornes de sortie dudit redresseur en pont (16, 35-36), ledit condensateur (39) servant à réduire le temps de retour desdites inductances (113, 114, 123, 124) pour effectuer ladite commutation à tension nulle.
16. Unité d'alimentation selon l'une quelconque des revendications précédentes 1 à 15, **caractérisée en ce qu'elle** est réalisée et dimensionnée de manière à être particulièrement convenable comme unité d'alimentation pour le traitement par plasma.

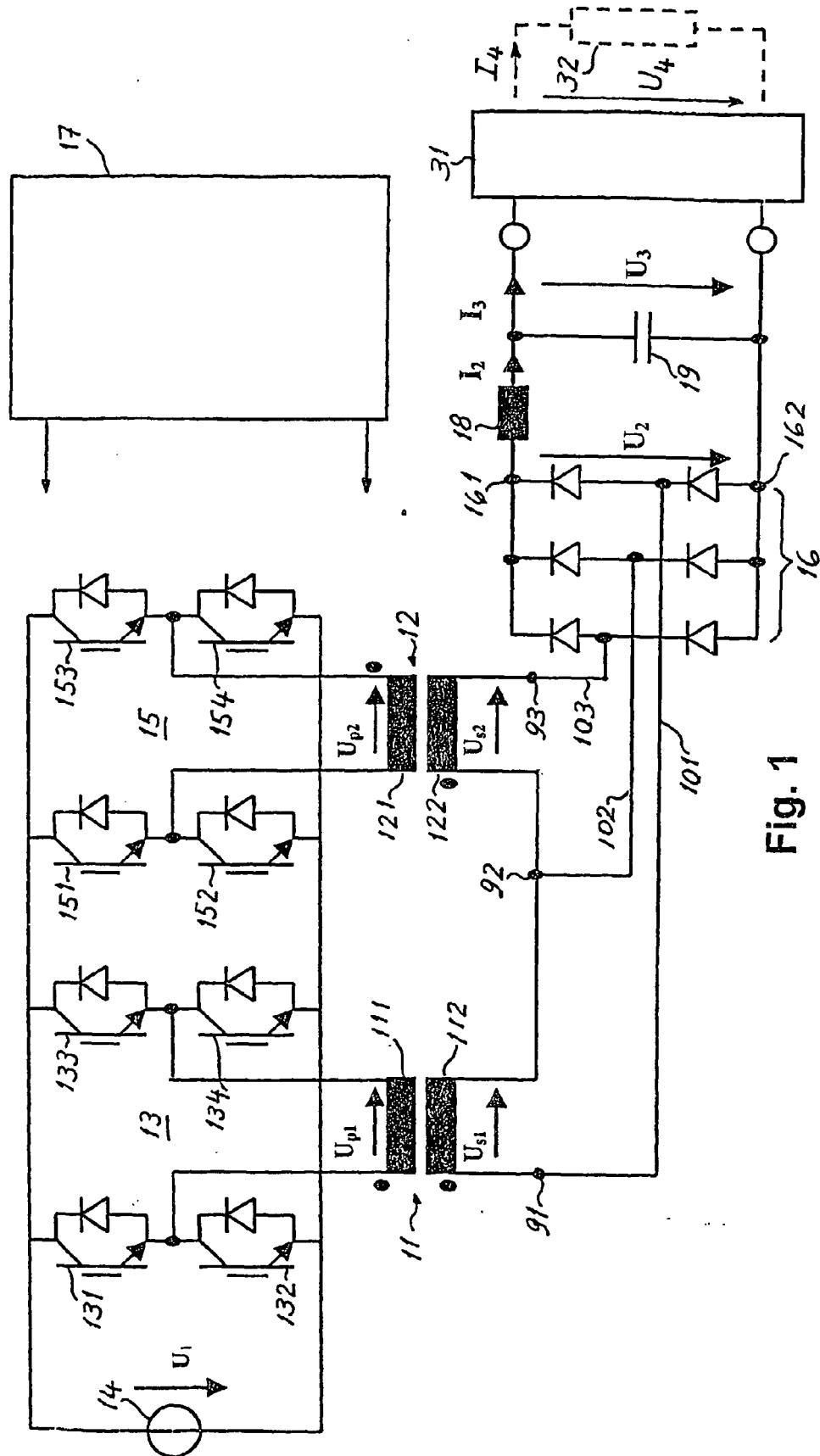


Fig. 1

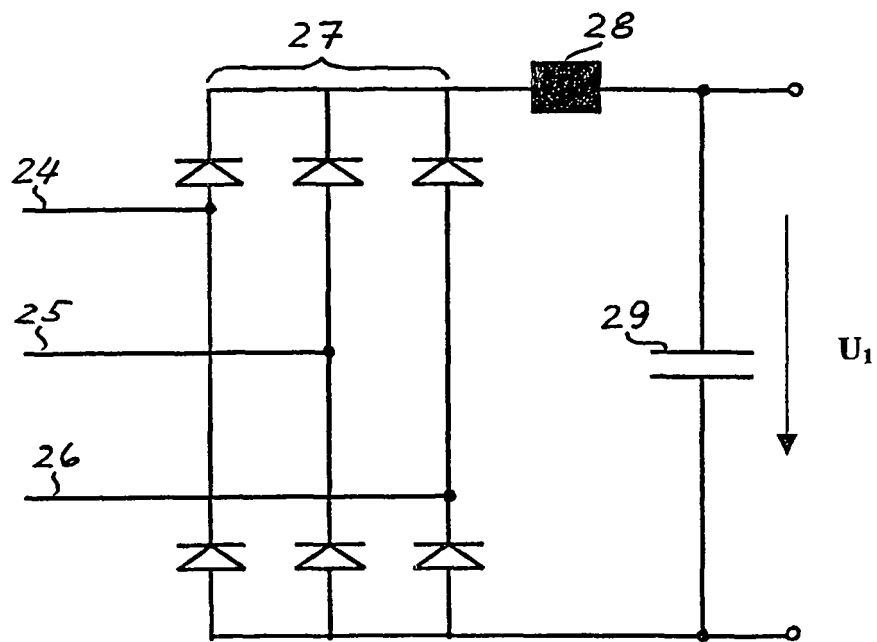


Fig. 2

$$\delta = 45^\circ, \alpha = 90^\circ$$

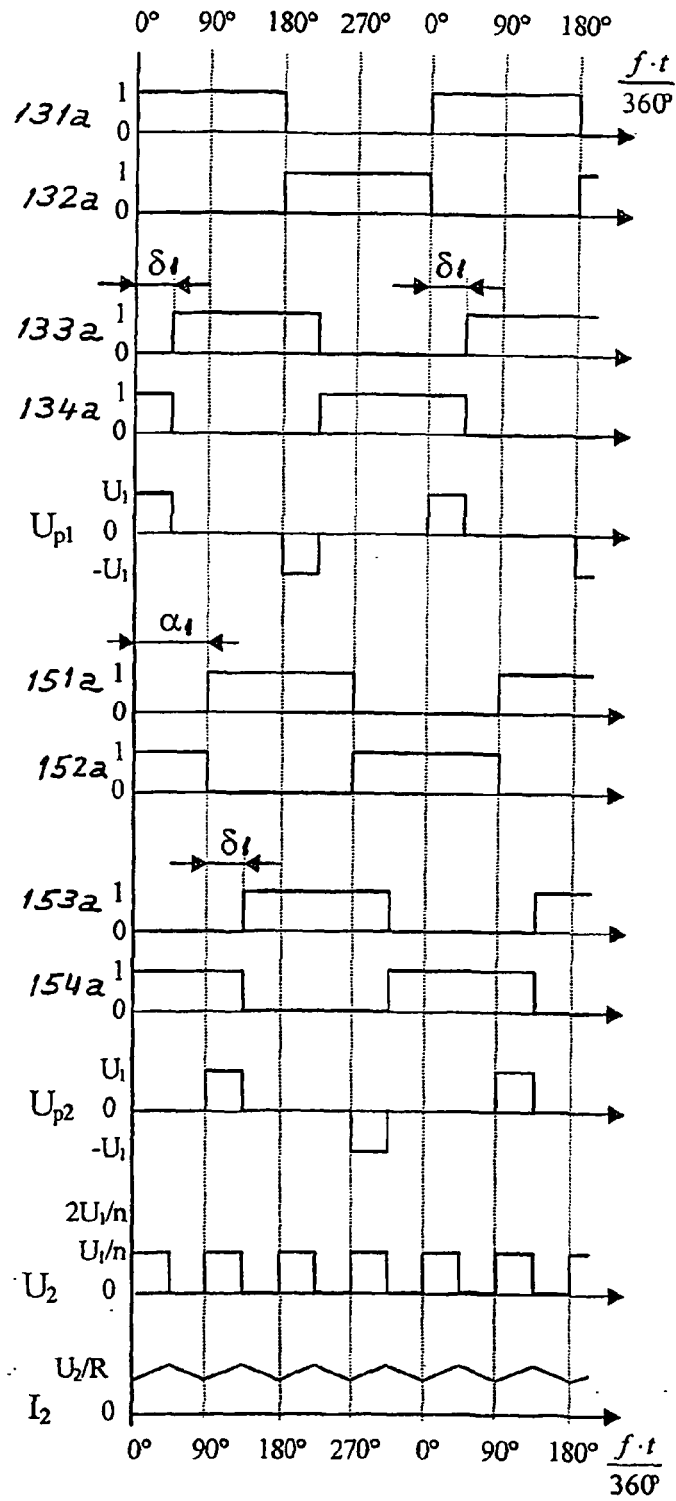


Fig. 3

$$\delta = 135^\circ, \alpha = 135^\circ$$

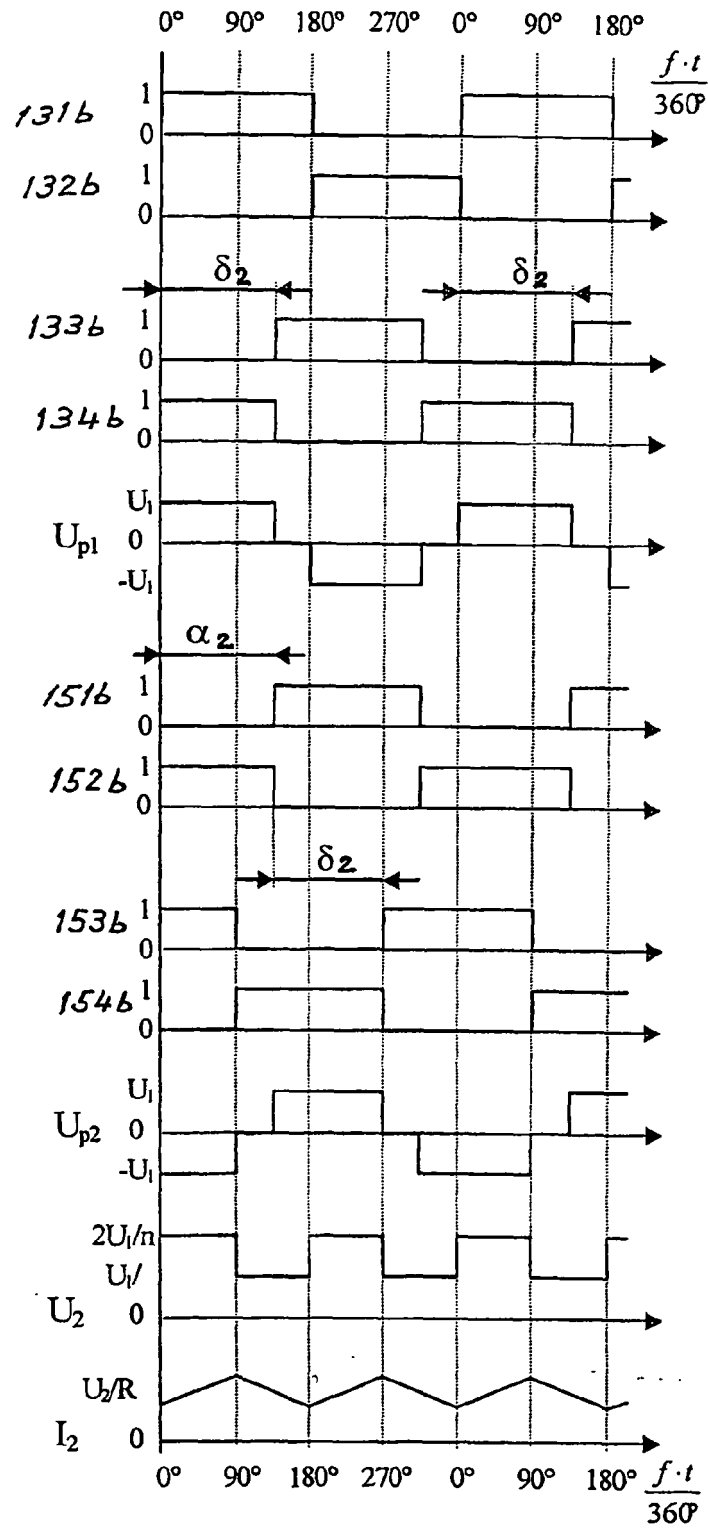


Fig. 4

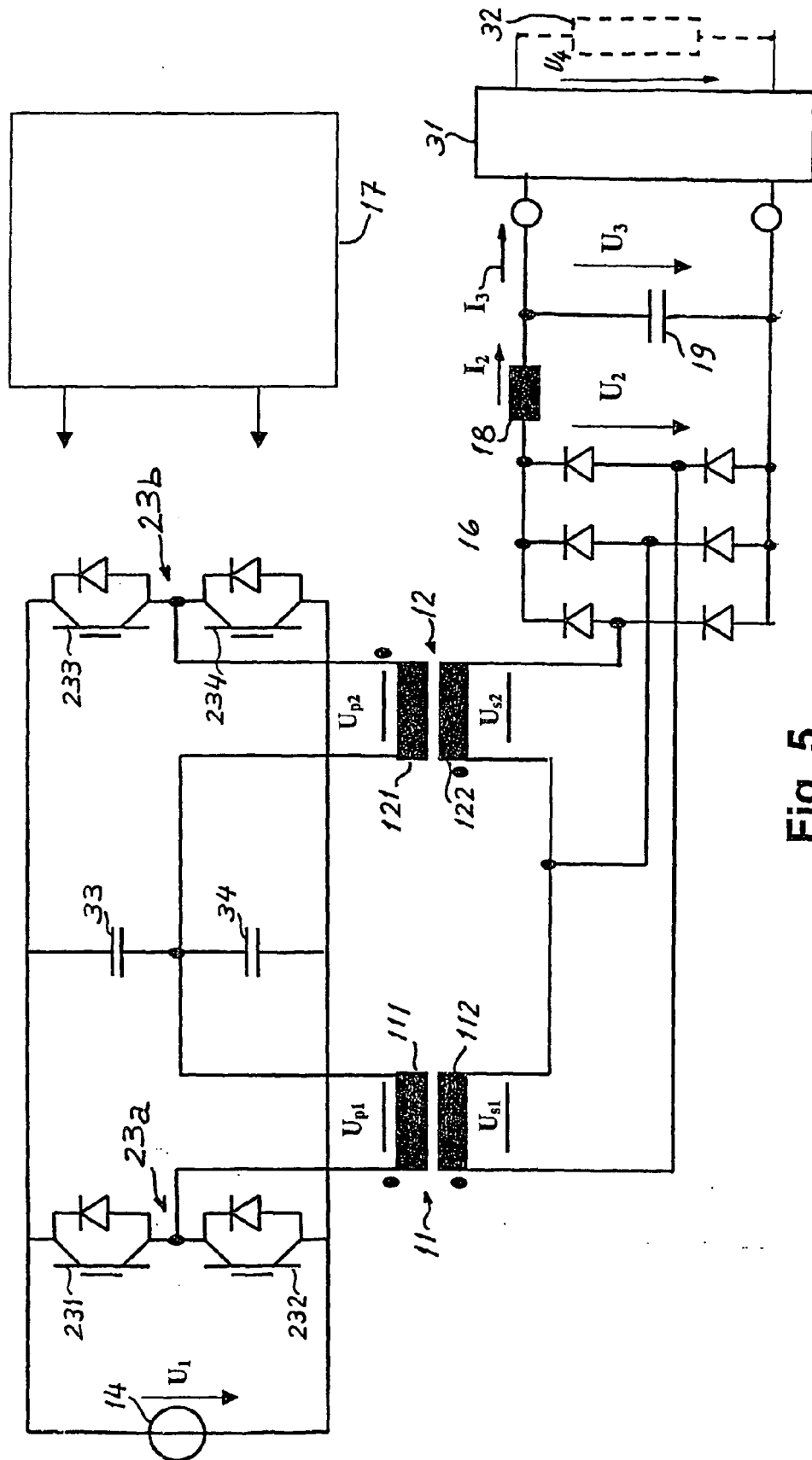


Fig. 5

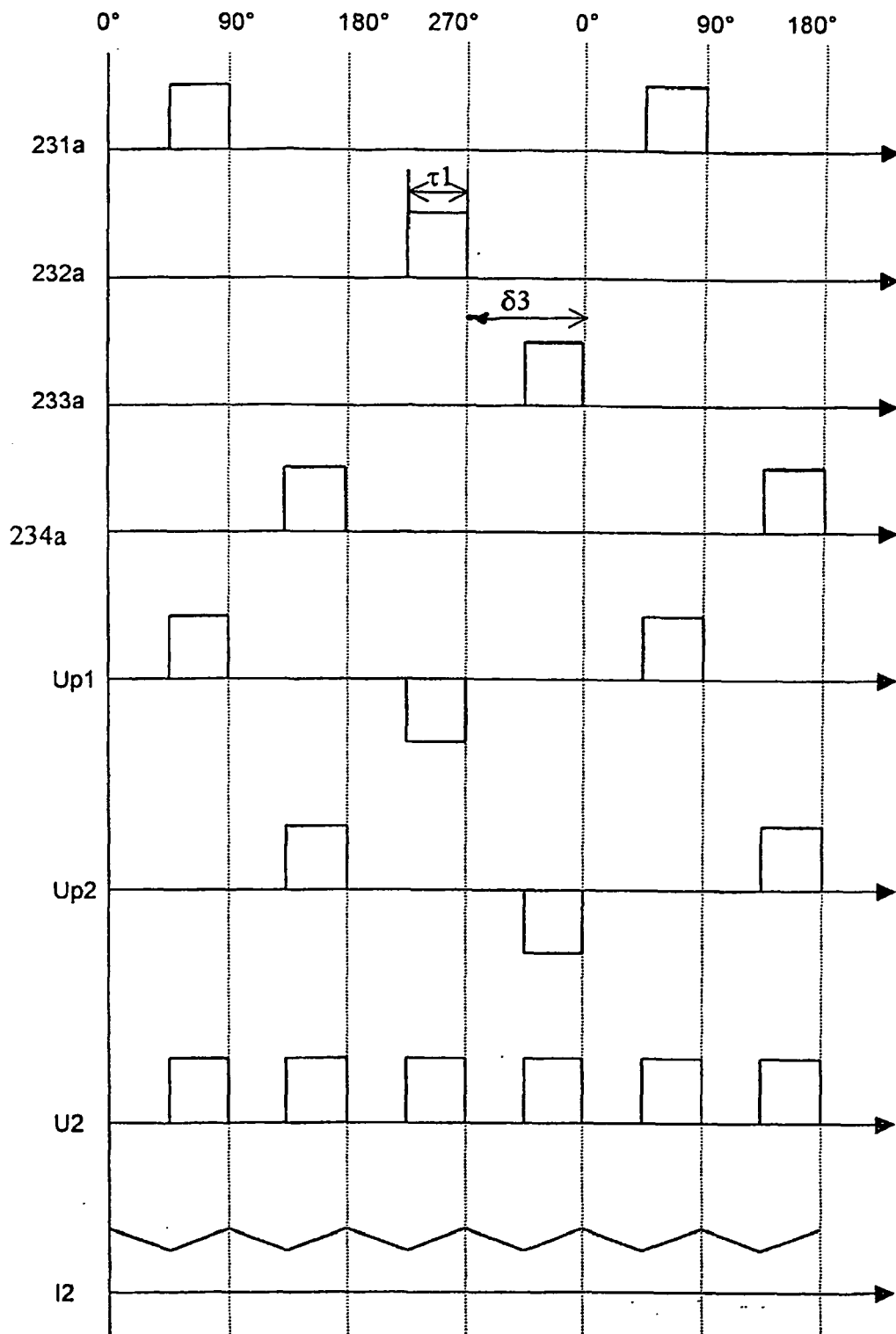


Fig. 6

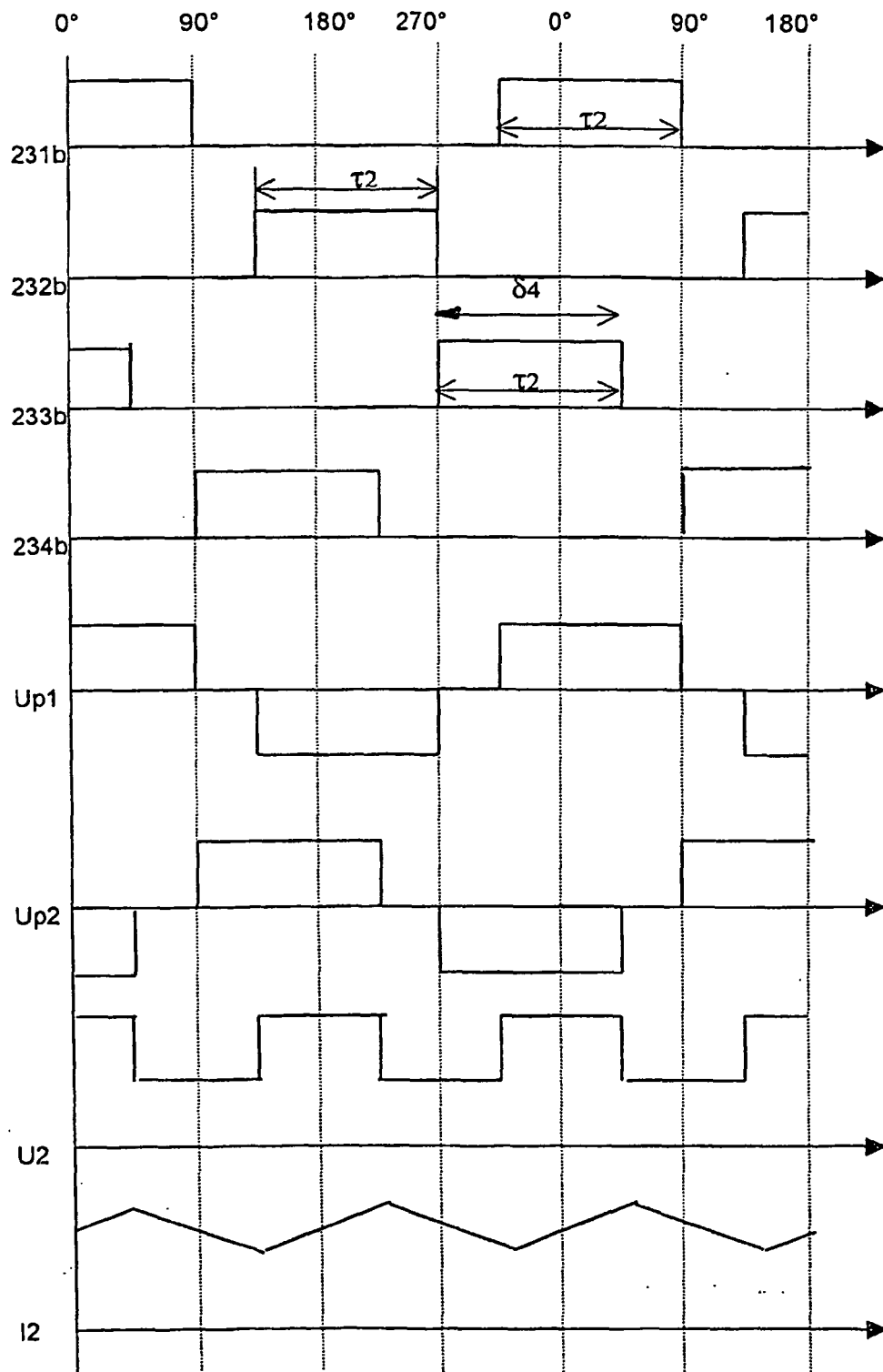


Fig. 7

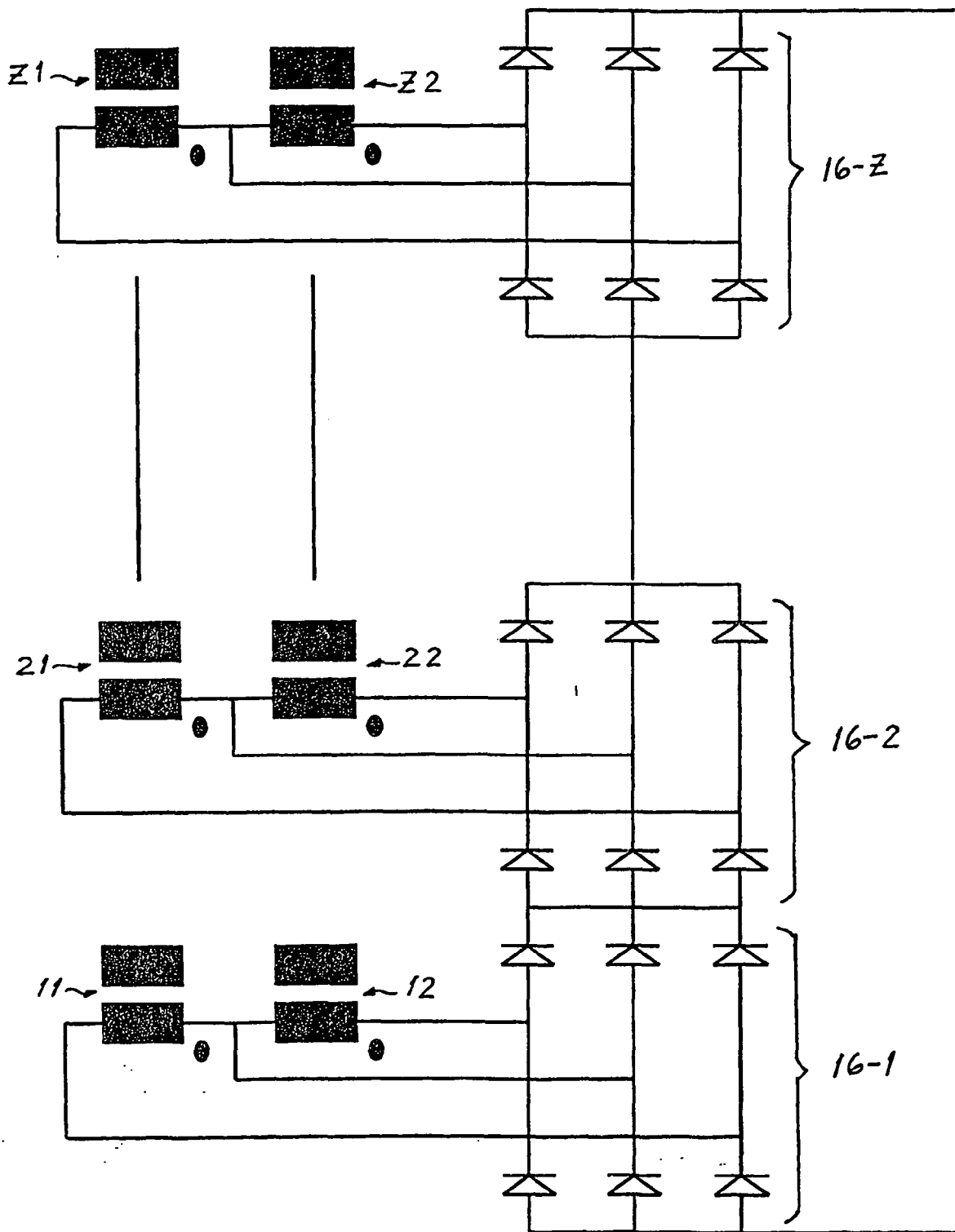


Fig. 8

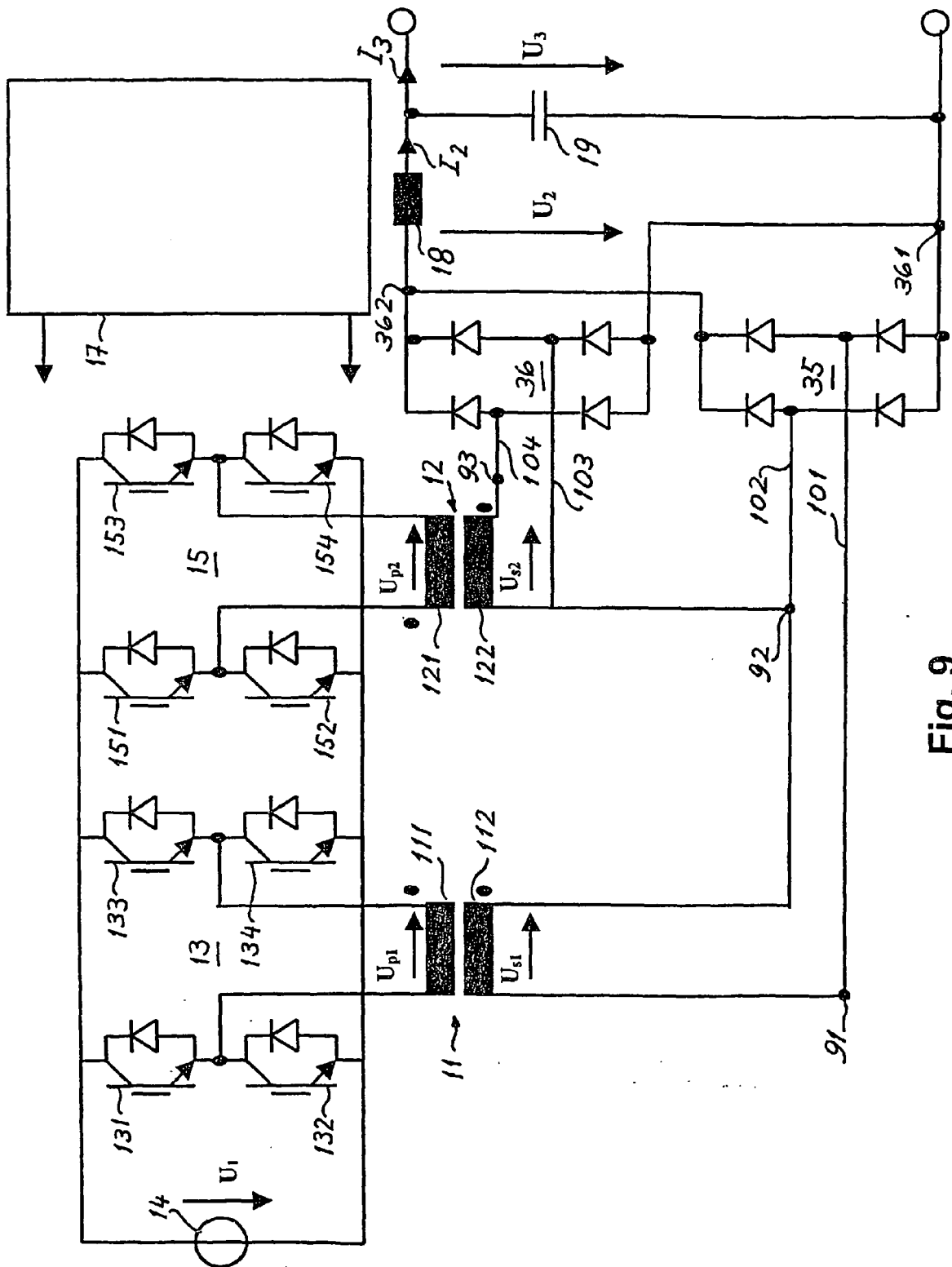


Fig. 9

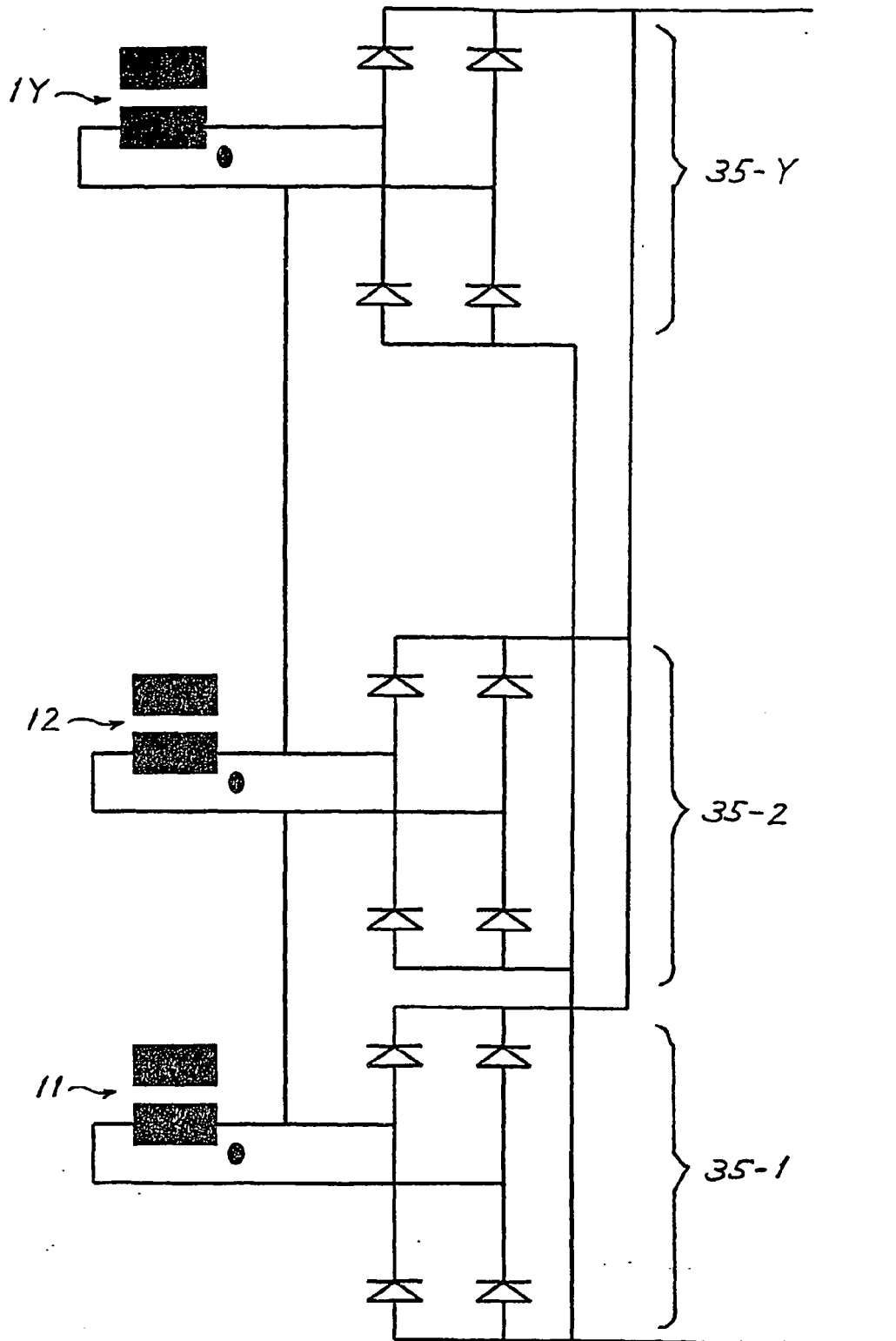


Fig. 10

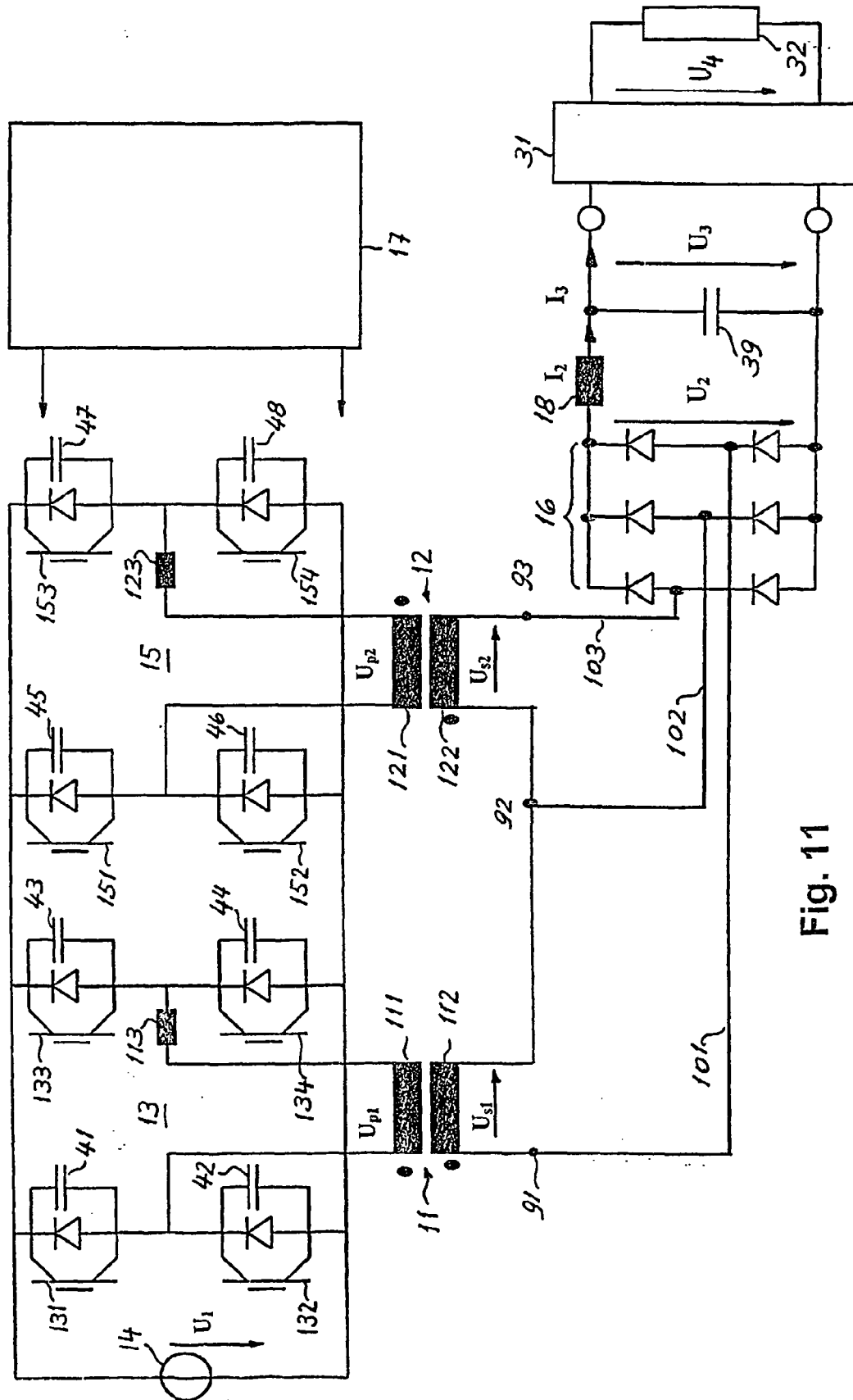


Fig. 11

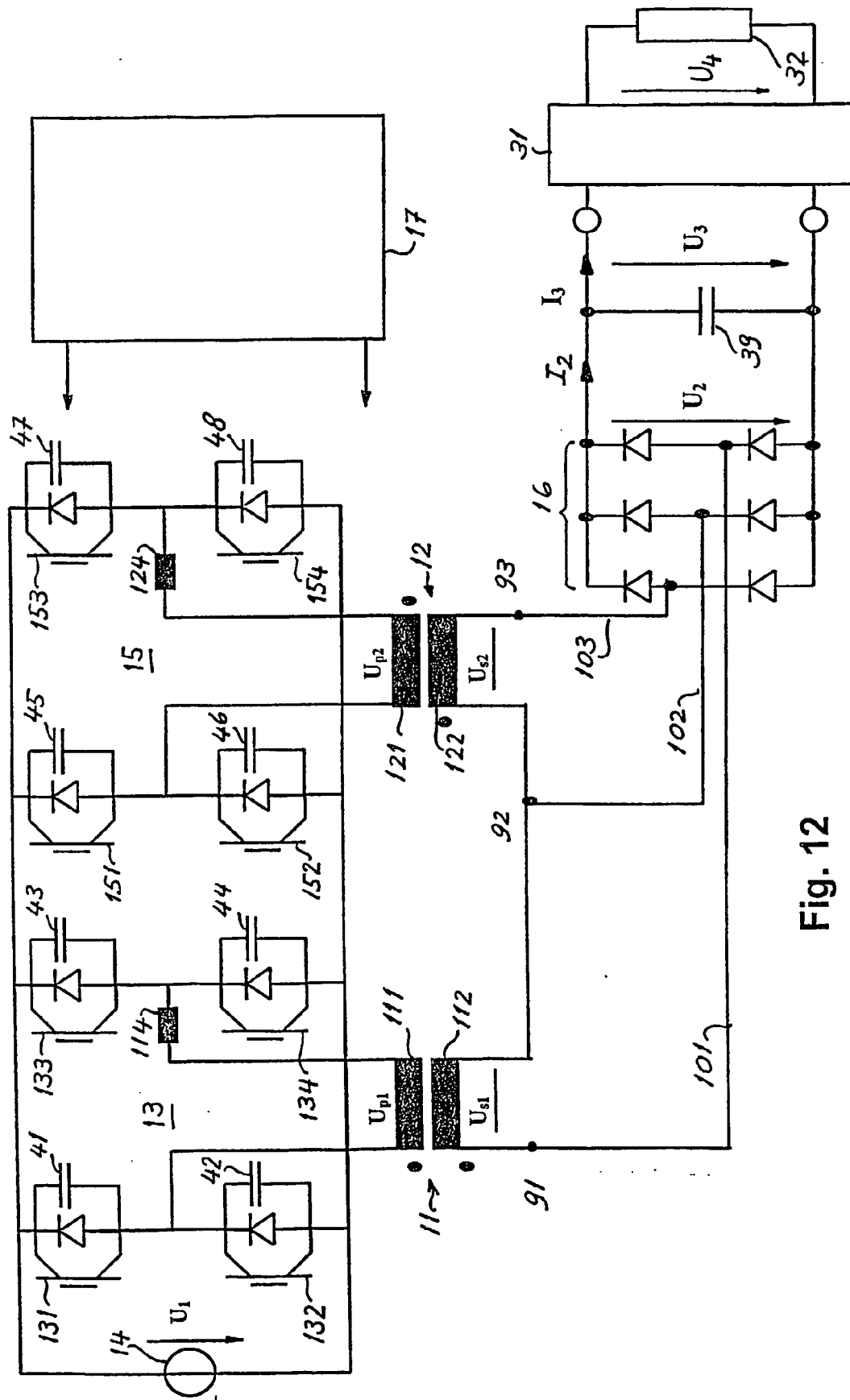


Fig. 12

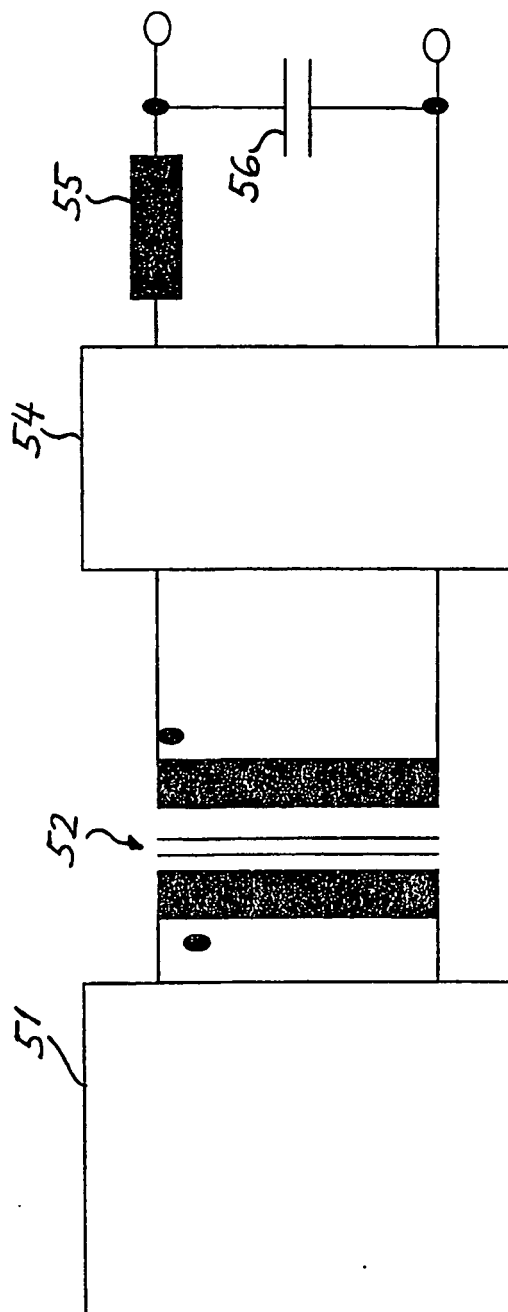


Fig. 13

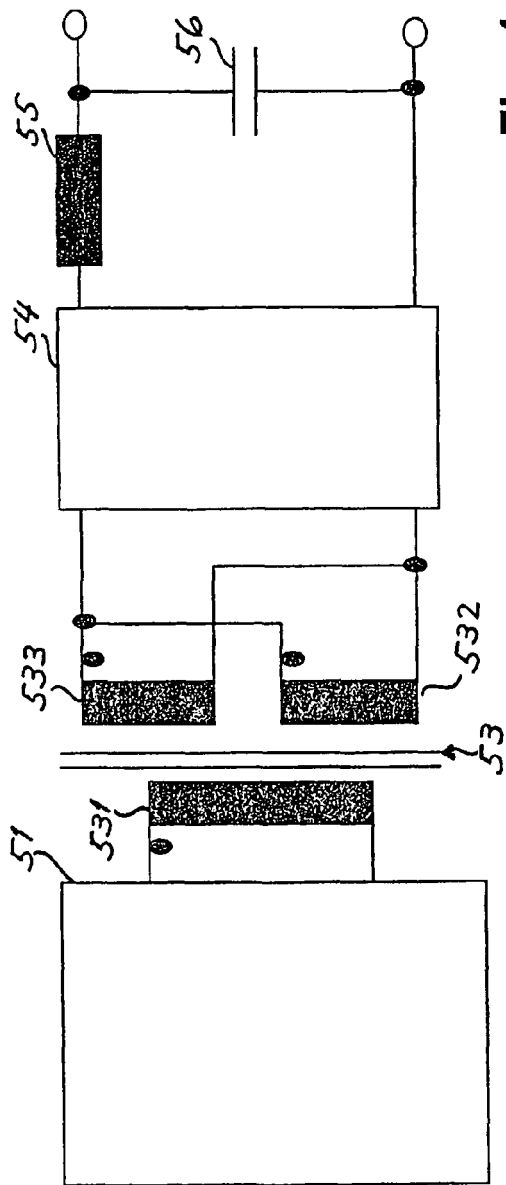


Fig. 14

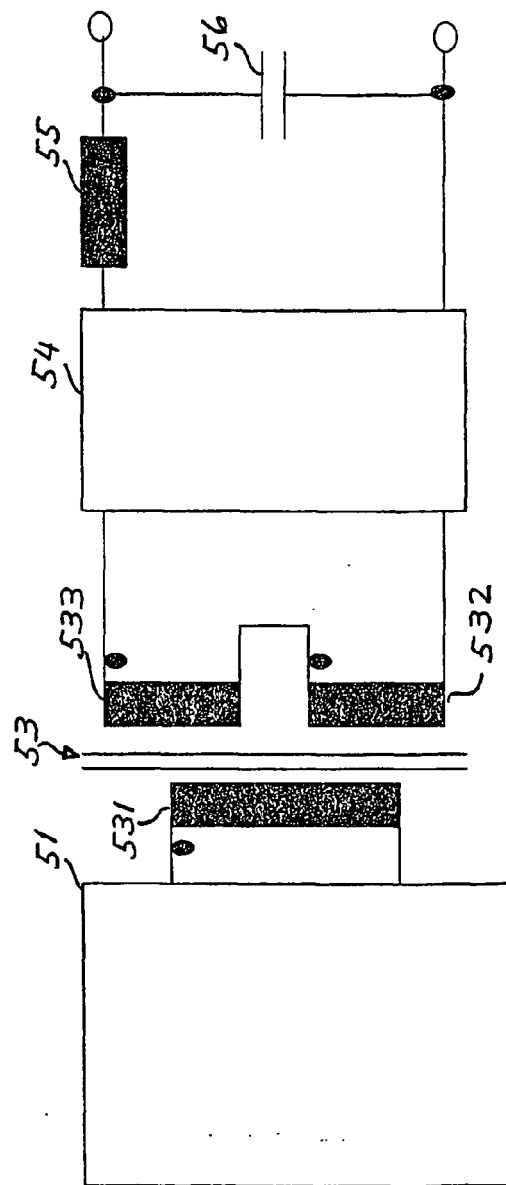


Fig. 15

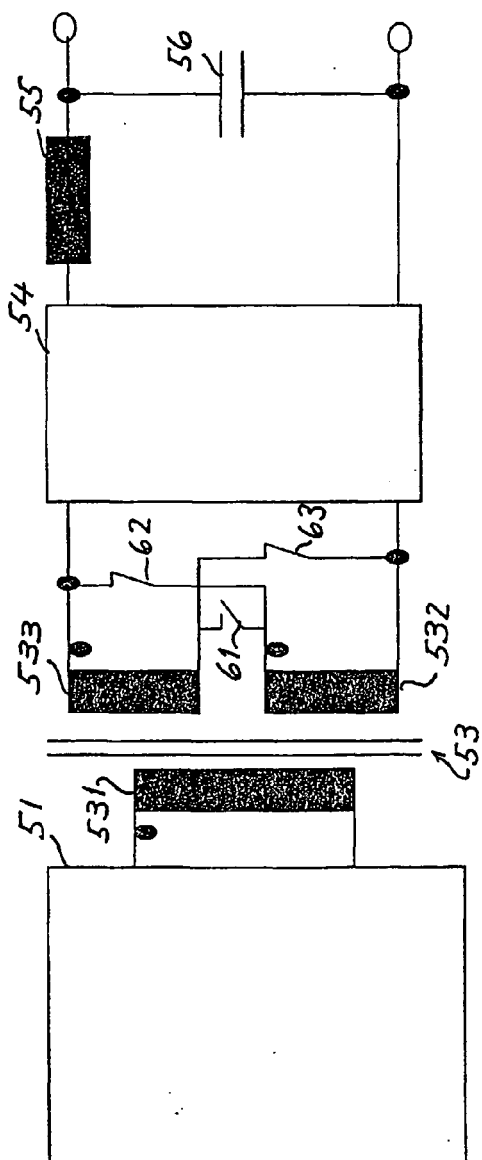


Fig. 16

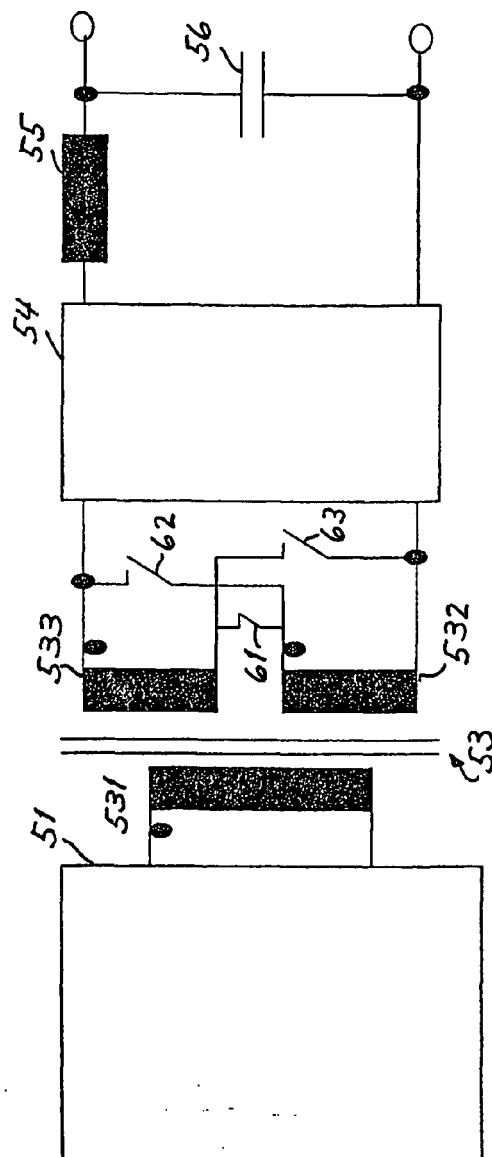


Fig. 17

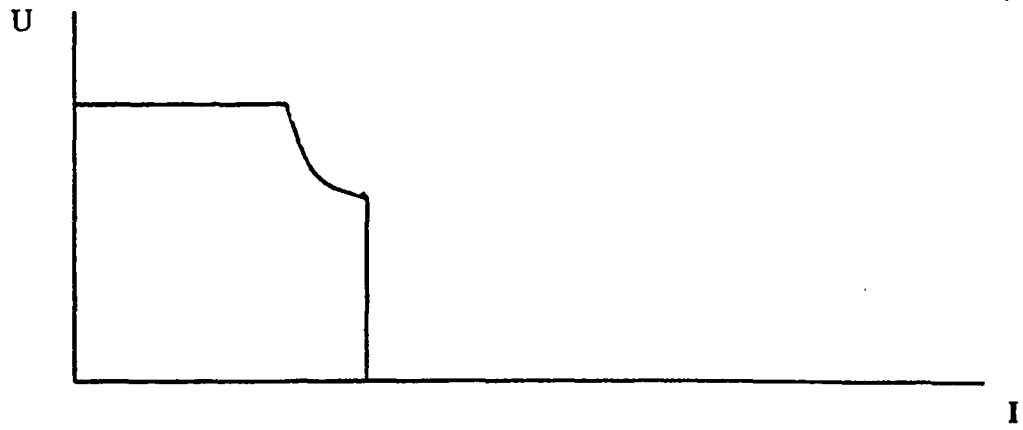


Fig. 18

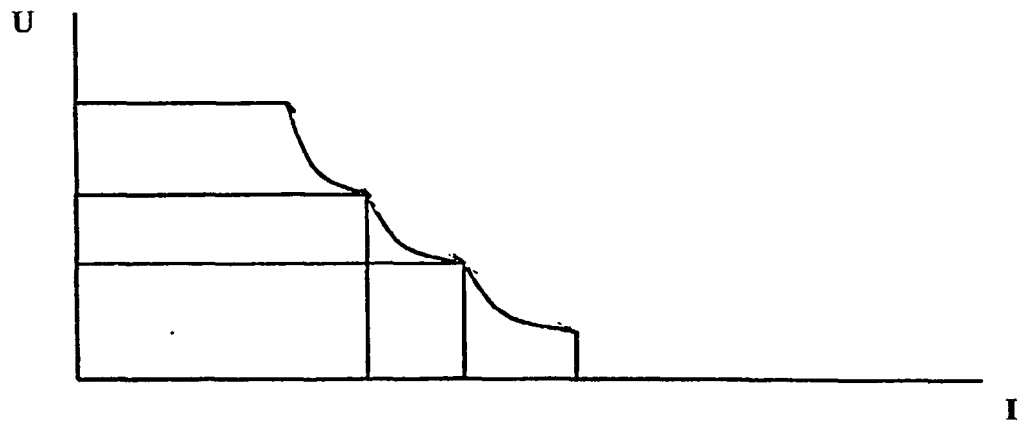


Fig. 19

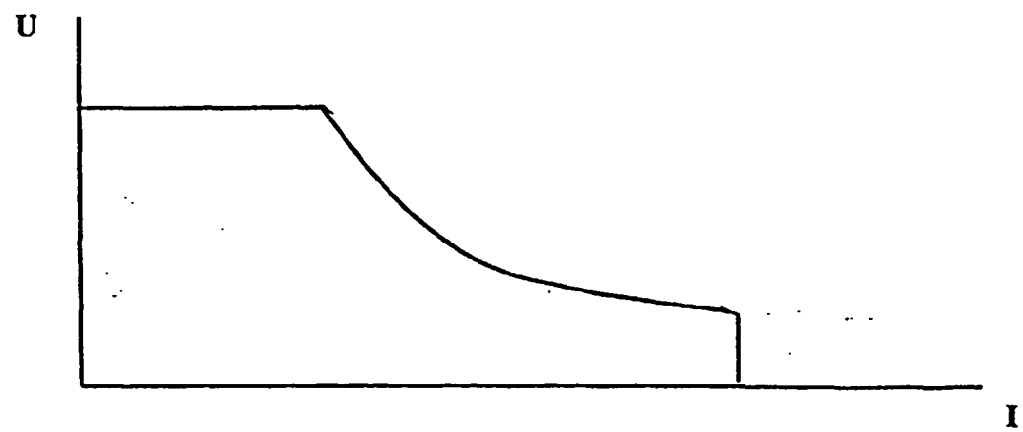


Fig. 20

REFERENCES CITED IN THE DESCRIPTION

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Non-patent literature cited in the description

- **Annual Power Electronics specialists Conference.** *Annual Power Electronics specialists Conference*, 2000, vol. 1, 179-184 [0009]
- *Annual Power Electronics Specialists Conference*, 1999, vol. 1, 433-438 [0010]