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(54) **DC-AC CONVERSION CIRCUIT TOPOLOGIE**

DC-AC-WANDLERSCHALTUNGSTOPOLOGIE

TOPOLOGIE DE CIRCUIT À CONVERSION CONTINU-ALTERNATIF

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(56) References cited:
**WO-A2-2012/146414** **US-A- 5 355 294**
**US-A1- 2012 063 184**



EP 3 576 283 B9

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## Description

**[0001]** This application claims priority to U.S. provisional application no. 61/785,958, filed March 14, 2013.

## Field

**[0002]** The present disclosure relates generally to voltage converter systems, in particular to systems adapted to convert direct-current (DC) voltages to alternating-current (AC) voltages and *vice versa.*

## Background

**[0003]** A DC-AC voltage converter is an electrical system that changes a DC voltage to an AC voltage. The converted AC voltage may have any desired voltage level, waveform and frequency with the use of appropriate transformers, switching, filtering and control circuits. DC-AC voltage converters are used in a wide range of applications, from small switching power supplies in electronic devices such as computers to large electric utility high-voltage direct current applications that transport bulk power. DC-AC voltage converters are also commonly used to supply AC power from DC sources such as solar panels or batteries.

**[0004]** Fig. 1 shows a typical prior art DC-AC voltage converter 10, which operates at a relatively low frequency. Voltage converter 10 is relatively simple, but it suffers from significant disadvantages. A first disadvantage is cost, because it uses a low-frequency transformer 12 that requires a relatively large amount of copper for transformer windings. In recent years the cost of copper has increased, while the cost of power semiconductors has decreased. This trend is expected to continue. In addition, a low-frequency transformer has relatively low efficiency when it is configured with a relatively high winding turns ratio and is used for voltage step-up. An example of such configurations is a DC-AC voltage converter with a step-up transformer having a turns ratio of about 19:1 or more and a relatively low input voltage power source, for example about 10 to 20 volts DC.

**[0005]** WO 2012/146414 A2 discloses a DC/AC converter comprising a DC/DC stage and a DC/AC stage.

## Summary

**[0006]** Given the foregoing, it is desirable to perform voltage conversion with a relatively high-frequency transformer driven by suitable power switching semiconductors. In one embodiment the present invention is a DC-AC voltage converter capable of operating with a relatively low DC voltage source input, such as from a battery power supply.

**[0007]** In some embodiments of the present invention the DC-AC voltage converter may be bidirectional, thereby capable of receiving an AC voltage signal and generating an output DC voltage signal. This arrangement is useful, for example, for charging a battery from an AC grid.

**[0008]** According to the invention, a transformer is utilized to provide electrical isolation for DC-AC and AC-DC conversion. An isolation transformer is used between a DC voltage input (e.g., a battery) and an AC voltage output. The voltage converters of the present invention may be generally divided into several types according to the type of transformer selected. For example, the isolation transformers may be relatively low-frequency, on the order of 50/60 Hertz (Hz). Preferably, the isolation transformers are relatively high-frequency, on the order of tens or more kilohertz (kHz).

**[0009]** An aspect out of the scope of the present invention is a voltage converter system that includes a first, high-frequency, DC-AC voltage converter configured to receive a first DC voltage signal and generate a first AC voltage signal. A DC link is configured to receive the first AC voltage signal and convert the first AC voltage signal to a second DC voltage signal. A second DC-AC voltage converter is configured to receive the second DC voltage signal and generate a second AC voltage signal.

**[0010]** Another aspect out of the scope of the present invention is a voltage converter system that includes a DC-AC voltage converter configured to receive a DC voltage signal and generate a first, relatively high-frequency, AC voltage signal. An AC-AC voltage converter is configured to receive the first AC voltage signal and generate a second AC voltage signal. The frequency of the second AC voltage signal is preferably lower than the frequency of the first AC voltage signal.

**[0011]** An aspect of the present invention is a voltage converter system that includes a first voltage converter portion that is configured to receive a DC voltage signal and convert the DC voltage signal to pulses of DC voltage. A second voltage converter portion is configured to receive the pulses of DC voltage and convert the pulses of DC voltage to a relatively low-frequency AC voltage signal. The voltage converter system is selectably configurable as a DC-AC voltage converter or an AC-DC voltage converter. In some embodiments of the present invention the first voltage converter portion includes a Ćuk-type voltage converter and a single-ended primary inductor converter (SEPIC) voltage converter, the Ćuk-type voltage converter and the SEPIC voltage converter being electrically combined to operate cooperatively.

## Brief Description of the Drawings

**[0012]** Further features of the inventive embodiments will become apparent to those skilled in the art to which the embodiments relate from reading the specification and claims with reference to the accompanying drawings, in which:

Fig. 1 is an electrical schematic diagram of a typical prior art DC-AC voltage converter;

Fig. 2 is an electrical schematic diagram of a DC-AC voltage converter system with a DC link according to an example out of the scope of the present invention;

Fig. 3 is an electrical schematic diagram of a DC-AC voltage converter system without a DC link according to another example out of the scope of the present invention;

Fig. 4 is an electrical schematic diagram of a voltage converter configurable for operation as either a DC-AC or an AC-DC voltage converter according to an embodiment of the present invention;

Fig. 5 is an electrical schematic diagram showing details of a first portion of the voltage converter of Fig. 4;

Fig. 6 is a graph showing the general waveform of certain electrical signals generated by the circuit of Fig. 5;

Fig. 7 is an electrical schematic diagram showing details of a second portion of the voltage converter of Fig. 4;

Fig. 8 is an electrical schematic diagram of a Ćuk-type voltage converter;

Fig. 9 is an electrical schematic diagram of a single-ended primary inductor converter voltage converter;

Fig. 10 is an electrical schematic diagram of the voltage converters of Figs. 8 and 9 electrically combined together in a new arrangement in accordance with an embodiment of the present invention, providing for a reduced total component count;

Fig. 11 is an electrical schematic diagram of the voltage converter of Fig. 10 incorporating several refinements; and

Fig. 12 is an electrical schematic diagram of a voltage converter according to yet another embodiment of the present invention.

## Detailed Description

**[0013]** Fig. 2 shows a DC-AC voltage converter system 100 having a first, high-frequency, DC-AC voltage converter 102 according to an example out of the scope of the present invention. First DC-AC voltage converter 102 receives at an input 103 a first DC voltage signal. A first, relatively high-frequency, AC voltage signal 104 generated by a transformer 105 of first DC-AC voltage converter 102 is supplied to a DC-link 106 that converts the first AC voltage signal to a second DC voltage signal 108. Second DC voltage signal 108 is coupled to a second DC-AC voltage converter 110 that converts second DC voltage signal 108 to a second AC voltage signal, output AC voltage signal 112. Output 112 may have either low-frequency components, high-frequency components, or both low- and high-frequency components.

**[0014]** An optional electrical filter 114 provides filtering of AC output voltage signal 112 to remove high-frequency components and/or limit electromagnetic interference (EMI) caused by the AC output voltage signal, resulting in a filtered AC output voltage signal 116. For certain applications where power quality is not a significant issue (such as a motor drive, as one example) a filter 114 configured to remove high-frequency components may be omitted.

**[0015]** Fig. 3 shows a DC-AC voltage converter system 200 according to another example out of the scope of the present invention. A first AC voltage signal 202 generated by a DC-AC voltage converter 204 is supplied to an AC-AC voltage converter 206 that converts the first AC voltage signal to a second AC voltage signal, output AC voltage signal 208. An electrical filter 210 provides filtering of AC output voltage signal 208 to reduce EMI caused by the AC output voltage signal, resulting in a filtered AC output voltage signal 211. First AC voltage signal 202 is a relatively high-frequency voltage signal, while second AC voltage signal 208 is a relatively low-frequency voltage signal output from voltage converter system 200.

**[0016]** With reference to Figs. 2 and 3 together, voltage converter system 100 provides relatively efficient voltage conversion, but compared to voltage converter system 200 it is more complex and more expensive to produce. However, the performance of voltage converter system 200 depends in part upon the operating conditions of a transformer 212. Fig. 3 shows a topology wherein transformer 212 operates under regulation, with a relatively high turns ratio. In this case efficiency of voltage converter system 200 will be less and the voltage converter system will generate a relatively high level of EMI on the AC output voltage signal 208. Consequently, EMI filter 210 may require a number of relatively expensive components in order to be effective.

**[0017]** Fig. 4 shows a schematic diagram of a voltage converter system 300 according to an embodiment of the present invention. Voltage converter system 300 is configurable for operation as either a DC-AC or an AC-DC voltage converter and is suitable for low DC input voltages (e.g., on the order of about 8-16 VDC) at power levels of up to several kilowatts. Furthermore, voltage converter system 300 overcomes the disadvantages discussed above. Voltage converter system 300 may be implemented with a relatively low number of active semiconductor switches. In addition, a transformer 302 (comprising windings 302A, 302B) functions under extremely benign conditions (i.e., conditions favorable in that root-mean-square (RMS) current and RMS voltage are favorable for relatively low transformer losses). Finally, there is only a low level of EMI on the AC side.

**[0018]** The topology of voltage converter system 300 may be divided into two portions for the purpose of explanation. A first voltage converter portion, 400 shown in Fig. 5, provides pulses of DC voltage regulated from 0 volts to a predetermined maximum voltage, with a generally half-sinusoidal waveform as shown in Fig. 6. A second voltage converter portion 500, shown in Fig. 7, provides electrical isolation and conversion from the pulsed DC voltage of Fig. 6 to a predetermined relatively low-frequency AC voltage signal including, without limitation, about 120 VAC at a frequency of about 50/60 Hz.

**[0019]** With continued reference to Fig. 5, this power stage is a combination of two types of power converters. The first is a Ćuk-type voltage converter 600, shown in Fig. 8. The other is a single-ended primary inductor converter (SEPIC) voltage converter 700, shown in Fig. 9. The operational details of these voltage converters are well-known in the art and thus will not be further elaborated upon here. Both voltage converters have a number of common features. For example, each is capable of providing an output voltage from zero to several times higher than the input voltage. In addition, both are bidirectional.

**[0020]** One important difference between the Ćuk-type voltage converter and the SEPIC-type voltage converter is that the Ćuk-type voltage converter reverses the polarity of the input voltage while the SEPIC-type voltage converter does not. With reference again to Fig. 5, these characteristics may be utilized to advantage, to provide an output voltage from an appropriately paired and electrically combined Ćuk-type voltage converter and SEPIC-type voltage converter that is about twice the output voltage available from each voltage converter individually, each voltage converter providing about half of output power delivered by the electrically combined voltage converters. A further advantage of this arrangement is that doubling the output voltage in this manner aids to reduce the required primary-to-secondary winding turns ratio of isolation transformer 302.

**[0021]** With reference now to Figs. 8 and 9 together, switches 602, 702 respectively exhibit substantially the same operating characteristics. Likewise, inductors 604, 704 in Figs. 8 and 9 respectively exhibit substantially the same operating characteristics. Therefore, these components can be combined in an appropriately paired Ćuk-type voltage converter and SEPIC-type voltage converter to form the circuit 800 shown in Fig. 10. In Fig. 10, switch 802 replaces switches 602, 702 while inductor 804 replaces the inductors 604, 704. Thus, switch 802 and inductor 804 are common to both the Ćuk-type voltage converter and the SEPIC voltage converter. This results in one less active switch and one less inductor in an appropriately paired Ćuk-type voltage converter and SEPIC-type voltage converter, thereby reducing voltage converter cost. Circuit 800 may be substituted for circuit 400 in the system of Fig. 4.

**[0022]** Ćuk and SEPIC voltage converters have one common disadvantage in that neither provide forward power conversion. Rather, they use passive components such as capacitors and inductors for energy storage. Consequently, the efficiency of these voltage converters depends very much on the quality factor of the aforementioned passive components. The quality factor of capacitors are generally good, but the quality factor of inductors are often less than desirable and often tend to worsen under high-current and low-voltage operating conditions. To reduce losses and increase efficiency, system 800 may be modified, replacing inductor 804 with an inductor/transformer 904, as shown in the circuit 900 of Fig. 11. In this embodiment of the present invention when a switch 902 begins conducting forward power conversion will be provided by inductor/transformer 904, thereby increasing the efficiency of system 900 in comparison to system 800 of Fig. 10. Circuit 900 may be substituted for circuit 400 in the system of Fig. 4.

**[0023]** With reference again to Fig. 7, voltage converter portion 500 comprises a power stage which will provide isolation between the low voltage side and the high voltage side. This topology is a series-resonant voltage converter, which is bi-directional. The power transformer 302 in this case works under substantially benign conditions, with a generally trapezoidal voltage wave form and a generally sinusoidal current wave form. The transformer 302 leakage inductance is part of the resonant inductor or, optionally, may comprise the entire resonant inductor. All these features aid to keep efficiency and the commutation frequency as high as possible. This reduces the transformer size and reduces its cost, as well as total inverter cost, reducing the cost of EMI filters if used.

**[0024]** A voltage converter 1000 is shown in Fig. 12 according to yet another embodiment of the present invention. Like voltage converters 800 and 900, voltage converter 1000 may be substituted for circuit 400 in the system of Fig. 4.

**[0025]** Voltage converter 1000 includes a first inductor 1002 and a second inductor 1004 connected in series, the first and second inductors each having an input and an output. A first capacitor 1006 is electrically intermediate the first and second inductors 1002, 1004, a first terminal of the first capacitor being electrically connected to the output of the first inductor and a second terminal of the first capacitor being electrically connected to the input of the second inductor. A third inductor 1008 and a fourth inductor 1010 are connected in series, the third and fourth inductors each having an input and an output. A second capacitor 1012 is electrically intermediate the third and fourth inductors 1008, 1010, a first terminal of the second capacitor being electrically connected to the output of the third inductor and a second terminal of the second capacitor being electrically connected to the input of the fourth inductor. A first switch 1014 is coupled between the input of the first inductor 1002 and the output of the third inductor 1008. A second switch 1016 is coupled between the output of the first inductor 1002 and the input of the third inductor 1008. A rectifier 1018 is arranged such that an anode of the rectifier is electrically connected to the second terminal of the first capacitor 1006, a cathode of the rectifier being electrically coupled to the second terminal of the second capacitor 1012. A third switch 1020 is electrically connected in parallel with the rectifier 1018. Voltage converter 1000 is configured to receive a DC voltage signal at the inputs of the first and third inductors 1002, 1008 and to generate an AC voltage signal at the outputs of the second and fourth inductors 1004, 1010.

**[0026]** Voltage converter system 1000 may further include third capacitor 1022, the third capacitor being electrically intermediate the second and fourth inductors 1004, 1010. A first terminal of third capacitor 1022 is electrically connected to the output of the second inductor 1004 and a second terminal of the third capacitor is electrically connected to the output of the fourth inductor 1010.

**[0027]** The foregoing configuration of voltage converter system 1000 has the advantage of relatively low inductor current and a low switch current, similar to the embodiment of Fig 5, since there are two input inductors (1002 and 1008) rather than the single input inductor of the previously-described configurations, and also has a low number of switches similar to the embodiment of Fig. 10. It should be noted that voltage converter system 1000 has more input current ripple compared to the embodiment of Fig. 5, as half of the input current is discontinuous because it flows through the switches, it is important in this embodiment that the switches switch synchronously to eliminate voltage transients across the switches and losses.

**[0028]** Inductors 1002, 1008 of voltage converter system 1000 may optionally be coupled magnetically to allow current balancing to occur. The current in inductor 1008 and switch 1014, and in inductor 1002 and switch 1016, may not necessarily ramp up identically as these inductor-switch pairs are independent of one another. However, when switches 1014, 1016 are opened the current flows in a complete circuit through the output (i.e., "a" and "b" of Fig. 12) so the current in inductors 1002, 1008 must be substantially the same. Any error will result in the energy being dumped in the switches 1014, 1016 until the currents are substantially the same. If the windings 1002, 1008 are coupled the energy can transfer between the windings until the currents are substantially the same rather than the energy being lost.

**[0029]** In some embodiments of the present invention certain inductors of voltage converter system 1000 may be wound upon a common core. For example, inductors 1002, 1008 may be wound upon a common core. Similarly, inductors 1004, 1010 may be wound upon a common core. Winding the inductors upon a common core may provide certain advantages, such as a reduction in the overall size of the inductors.

**[0030]** One skilled in the art will appreciate that any suitable electronic components may be utilized for the circuits shown in the accompanying figures and described herein. For example, the switches may be any suitable types of power switching components including, without limitation, semiconductors such as bipolar junction transistors, field effect transistors and thyristors. Likewise, the diodes, capacitors, inductors and transformers shown in the accompanying figures may be any suitable types and values for a particular realization of the circuitry.

**[0031]** In addition, the circuits shown in the accompanying figures are simplified for purposes of explanation and are not intended to be limiting in any way. Accordingly, the circuits may include any suitable number and type of ancillary components including, without limitation, biasing, feedback and filtering components and circuitry as well as analog and/or digital monitoring, feedback and control circuitry.

**[0032]** While this invention has been shown and described with respect to a detailed embodiment thereof, it will be understood by those skilled in the art that changes in form and detail thereof may be made without departing from the scope of the claims of the invention.

## Claims

**1.** A voltage converter system (300) comprising:

a first voltage converter portion (400) configured to receive a DC voltage signal and convert the DC voltage signal to pulses of DC voltage;
and a second voltage converter portion (500) configured to receive the pulses of DC voltage and to convert the pulses of DC voltage to an AC voltage signal,
wherein the second voltage converter portion (500) comprises first, second, third and fourth switches and a first inductor (302A), the first, second, third and fourth switches adapted to receive the pulses of DC voltage and to commutate an alternating current through the first inductor (302A);
the voltage converter system (300) **characterized by**: the first inductor (302A) comprising a primary stage of a transformer and the second voltage converter portion (500) further comprising:

a second inductor (302B) and a third inductor, the second inductor (302B) comprising a secondary stage of the transformer, the second inductor (302B) connected in series with the third inductor,
the second inductor (302B) and the third inductor connected between first and second nodes;
a fifth switch connected between the first node and a third node;
a first diode and a second diode, the first node connected to a cathode of the first diode and a cathode of the second diode, an anode of the first diode connected to the third node and an anode of the second diode connected to a fourth node;
a sixth switch connected between the first and fourth nodes;
a third diode, the fourth node connected to an anode of the third diode and a cathode of the third diode connected to a fifth node;
a seventh switch connected between the

fourth and fifth nodes; a fourth diode, the third node connected to an anode of the fourth diode and a cathode of the fourth diode connected to a sixth node;
an eighth switch connected between the third and sixth nodes;
a first capacitor connected between the second and sixth nodes;
a second capacitor connected between the second and fifth nodes; and a third capacitor connected between the sixth and fifth nodes;
wherein the fifth, sixth, seventh, and eighth switches are adapted to commutate an alternating current through the third capacitor.

## Patentansprüche

**1.** Spannungswandlersystem (300), umfassend:

einen ersten Spannungswandlerabschnitt (400), der konfiguriert ist, um ein Gleichspannungssignal zu empfangen und das Gleichspannungssignal in Impulse von Gleichspannung umzuwandeln;
und einen zweiten Spannungswandlerabschnitt (500), der konfiguriert ist, um die Gleichspannungsimpulse zu empfangen und die Gleichspannungsimpulse in ein Wechselspannungssignal umzuwandeln, wobei der zweite Spannungswandlerabschnitt (500) einen ersten, zweiten, dritten und vierten Schalter, und einen ersten Induktor (302A) umfasst, der erste, zweite, dritte und vierte Schalter dazu ausgelegt sind, die Gleichspannungsimpulse zu empfangen und einen Wechselstrom durch den ersten Induktor (302A) zu kommutieren; wobei das Spannungswandlersystem (300) **dadurch gekennzeichnet ist, dass**:
der erste Induktor (302A) eine Primärstufe eines Transformators umfasst, und der zweite Spannungswandlerabschnitt (500) ferner umfasst:

einen zweiten Induktor (302B) und einen dritten Induktor, wobei der zweite Induktor (302B) eine Sekundärstufe des Transformators umfasst, der zweite Induktor (302B) in Reihe mit dem dritten Induktor geschaltet ist, der zweite Induktor (302B) und der dritte Induktor zwischen dem ersten und zweiten Knoten verbunden sind;
einen fünften Schalter, der zwischen dem ersten Knoten und einem dritten Knoten verbunden ist;
eine erste Diode und eine zweite Diode, wobei der erste Knoten mit einer Kathode der ersten Diode und einer Kathode der zweiten Diode verbunden ist, eine Anode der ersten Diode mit dem dritten Knoten verbunden ist, und
eine Anode der zweiten Diode mit einem vierten Knoten verbunden ist;
einen sechsten Schalter, der zwischen dem ersten und vierten Knoten verbunden ist;
eine dritte Diode, wobei der vierte Knoten mit einer Anode der dritten Diode verbunden ist, und
eine Kathode der dritten Diode mit einem fünften Knoten verbunden ist;
einen siebten Schalter, der zwischen dem vierten und fünften Knoten verbunden ist;
eine vierte Diode, wobei der dritte Knoten mit einer Anode der vierten Diode verbunden ist, und
eine Kathode der vierten Diode mit einem sechsten Knoten verbunden ist;
einen achten Schalter, der zwischen dem dritten und sechsten Knoten verbunden ist;
einen ersten Kondensator, der zwischen dem zweiten und sechsten Knoten verbunden ist;
einen zweiten Kondensator, der zwischen dem zweiten und fünften Knoten verbunden ist;
und einen dritten Kondensator, der zwischen dem sechsten und fünften Knoten verbunden ist;
wobei der fünfte, sechste, siebte und achte Schalter dazu ausgelegt sind, einen Wechselstrom durch den dritten Kondensator zu kommutieren.

## Revendications

**1.** Système convertisseur de tension (300) comprenant :

une première partie de convertisseur de tension (400) configurée pour recevoir un signal de tension continue et convertir le signal de tension continue en impulsions de tension continue ;
et une seconde partie de convertisseur de tension (500) configurée pour recevoir les impulsions de tension continue et convertir les impulsions de tension continue en un signal de tension alternative, dans lequel la seconde partie de convertisseur de tension (500) comprend des premier, deuxième, troisième et quatrième commutateurs et un premier inducteur (302A), les premier, deuxième, troisième et quatrième commutateurs étant adaptés pour recevoir les impulsions de tension continue et commuter un courant alternatif à travers le premier inducteur (302A) ; le système convertisseur de tension

(300) étant **caractérisé par** :
le premier inducteur (302A) comprenant un étage primaire d'un transformateur et la seconde partie de convertisseur de tension (500) comprenant en outre :

un deuxième inducteur (302B) et un troisième inducteur, le deuxième inducteur (302B) comprenant un étage secondaire du transformateur, le deuxième inducteur (302B) étant connecté en série au troisième inducteur, le deuxième inducteur (302B) et le troisième inducteur étant connectés entre les premier et deuxième noeuds ;
un cinquième commutateur connecté entre le premier nœud et un troisième noeud ;
une première diode et une deuxième diode, le premier nœud étant connecté à une cathode de la première diode et à une cathode de la deuxième diode, une anode de la première diode connectée au troisième nœud et
une anode de la deuxième diode connectée à un quatrième noeud ;
un sixième commutateur connecté entre les premier et quatrième noeuds ;
une troisième diode, le quatrième nœud étant connecté à une anode de la troisième diode et
une cathode de la troisième diode connectée à un cinquième noeud ;
un septième commutateur connecté entre les quatrième et cinquième noeuds ;
une quatrième diode, le troisième nœud étant connecté à une anode de la quatrième diode et
une cathode de la quatrième diode connectée à un sixième noeud ;
un huitième commutateur connecté entre les troisième et sixième noeuds ;
un premier condensateur connecté entre les deuxième et sixième noeuds ;
un deuxième condensateur connecté entre les deuxième et cinquième noeuds ;
et un troisième condensateur connecté entre les sixième et cinquième nœuds ;
dans lequel les cinquième, sixième, septième et huitième commutateurs permettent de commuter un courant alternatif à travers le troisième condensateur.

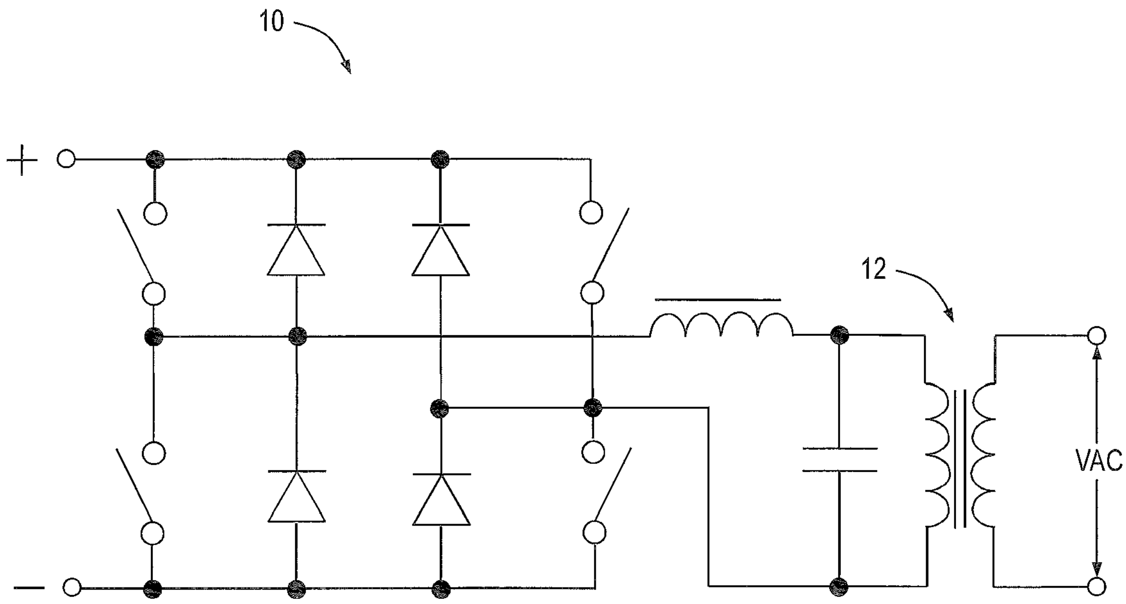



***Fig. 1***
***Prior Art***

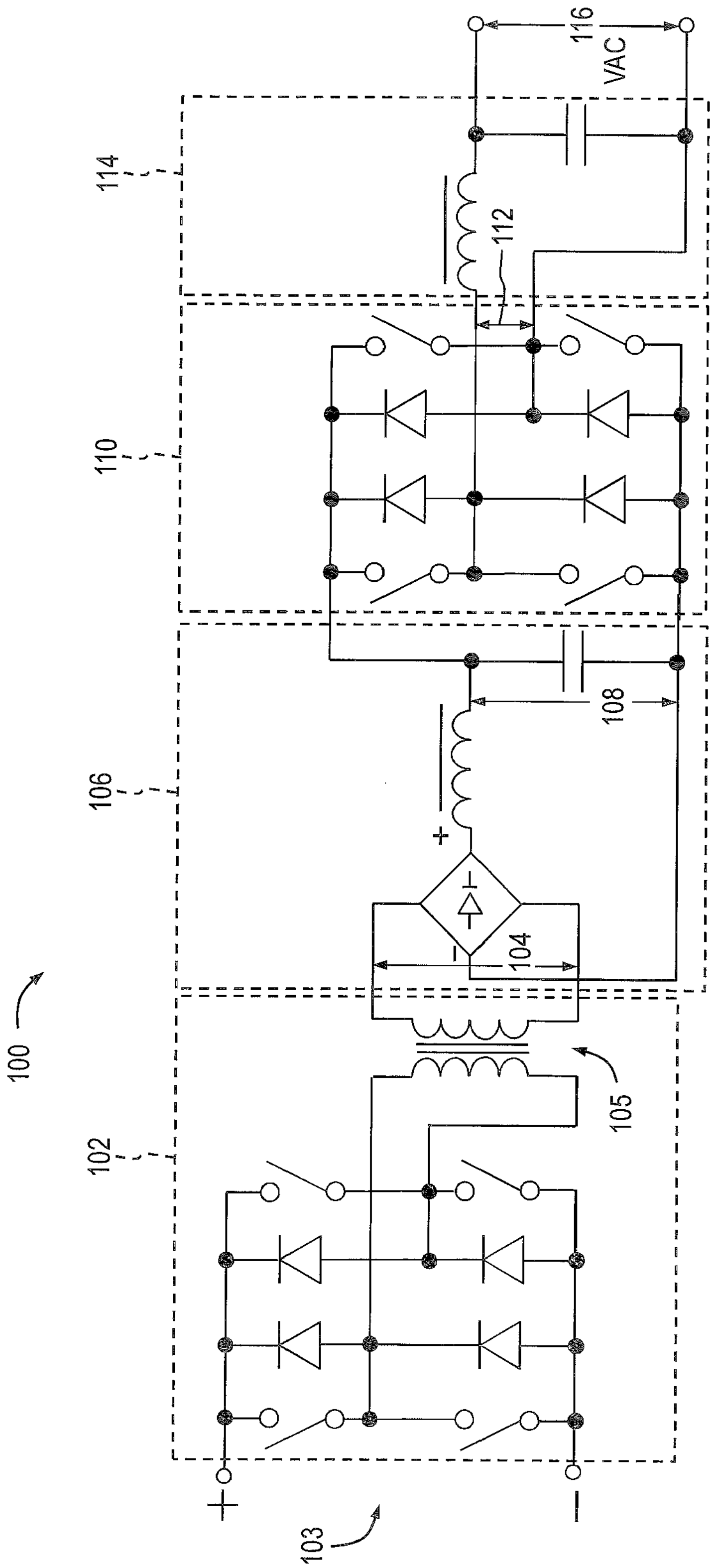



*Fig. 2*

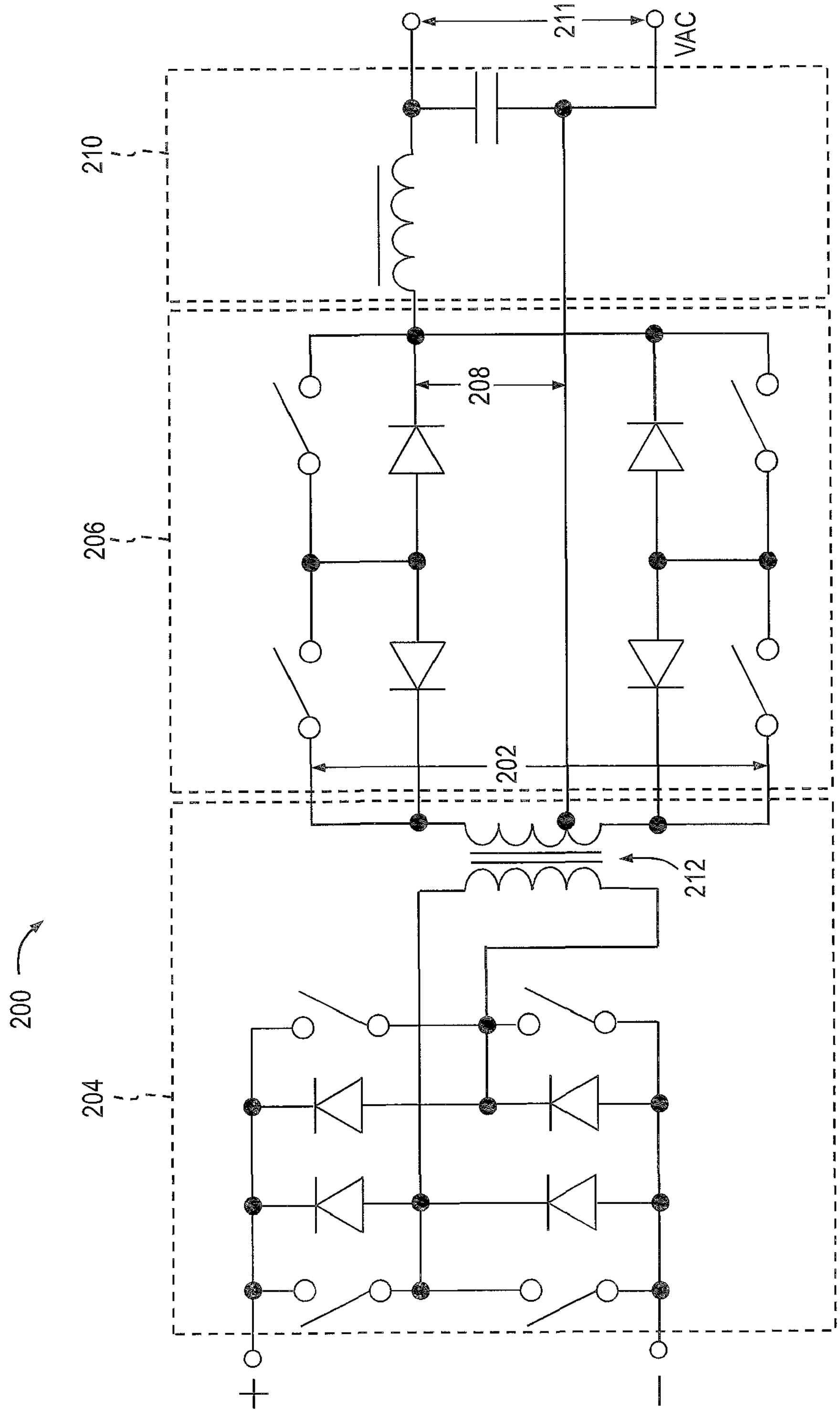



*Fig. 3*

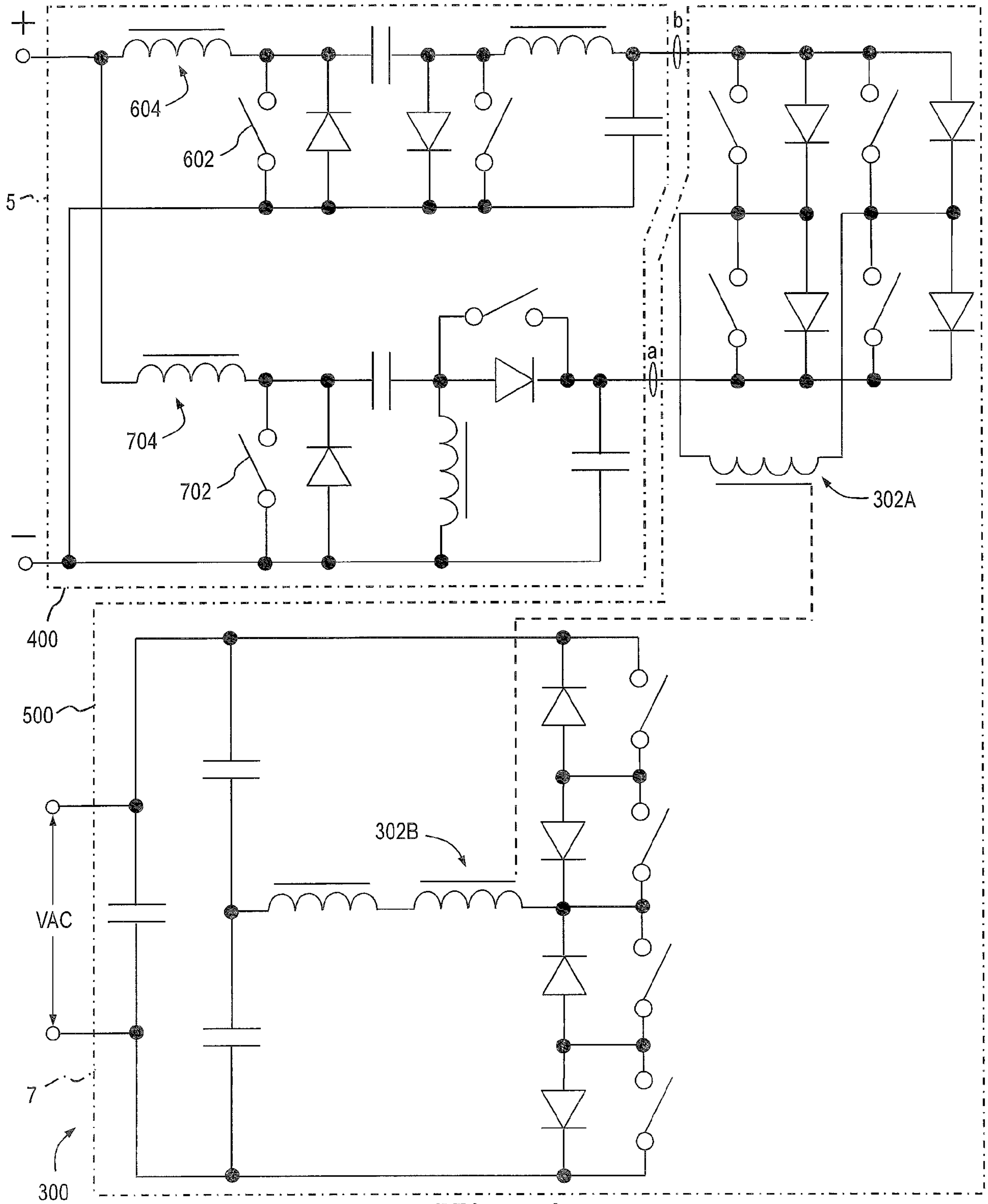



*Fig. 4*

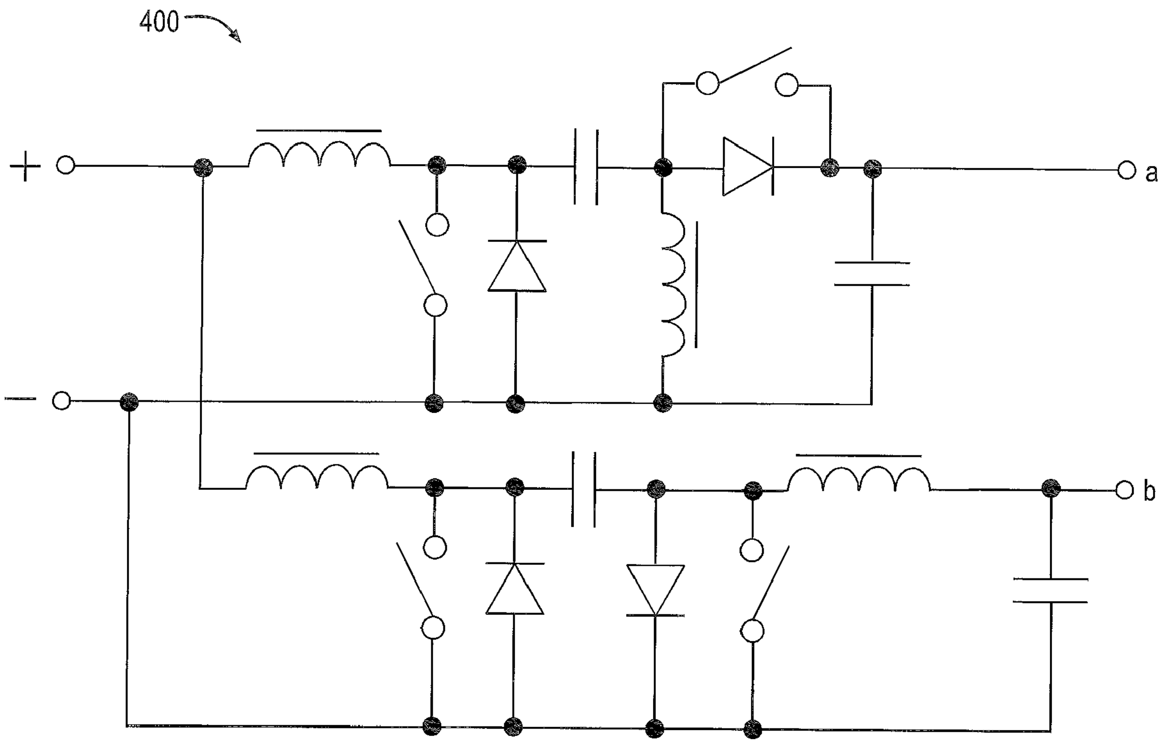



*Fig. 5*

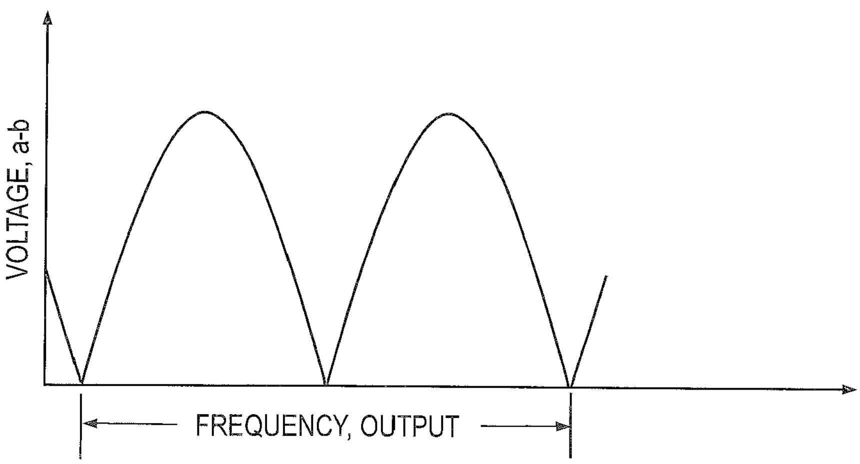



*Fig. 6*

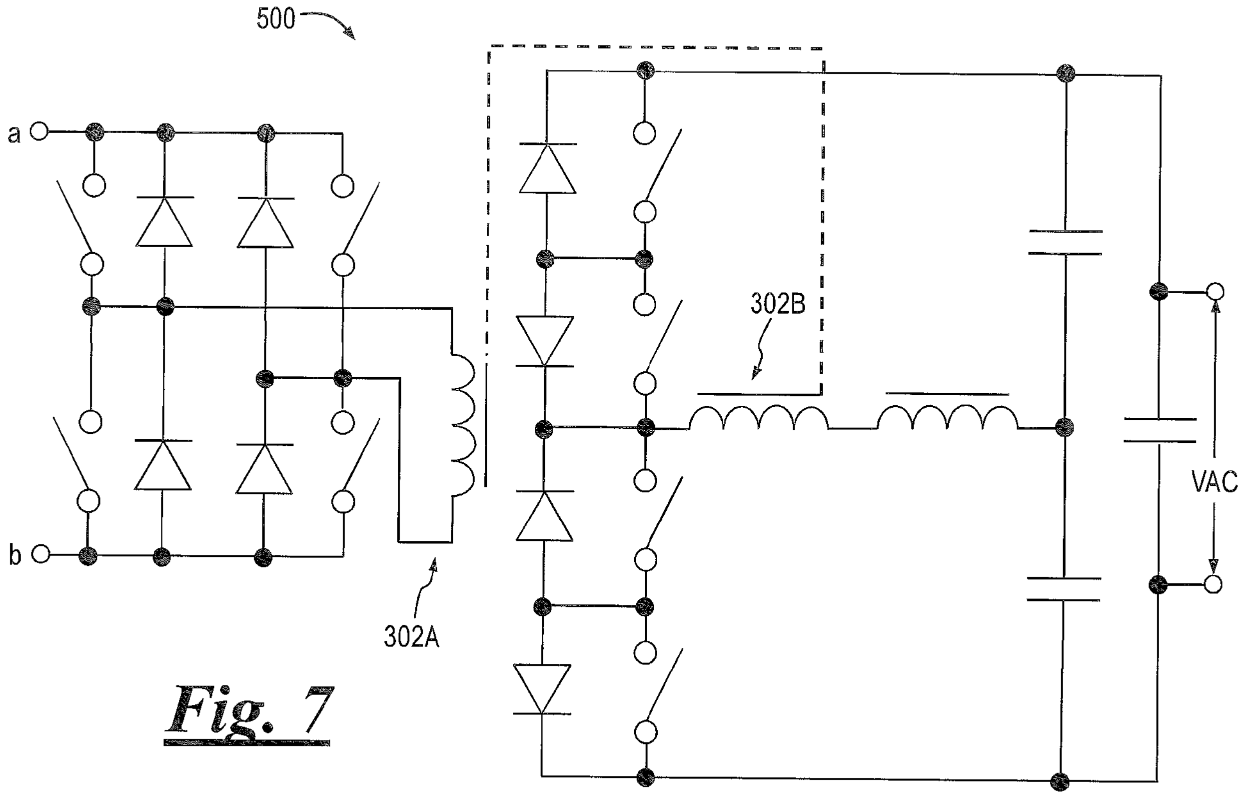



*Fig. 7*

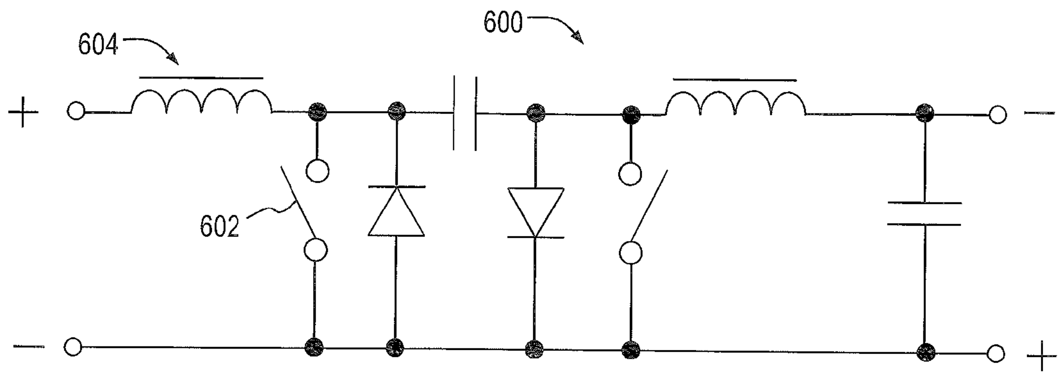



*Fig. 8*
*Prior Art*

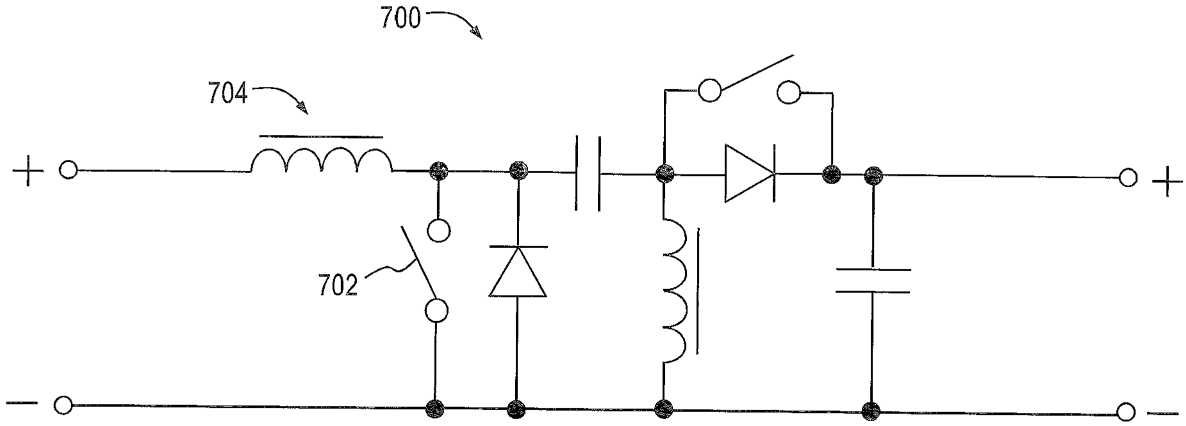



***Fig. 9***
***Prior Art***

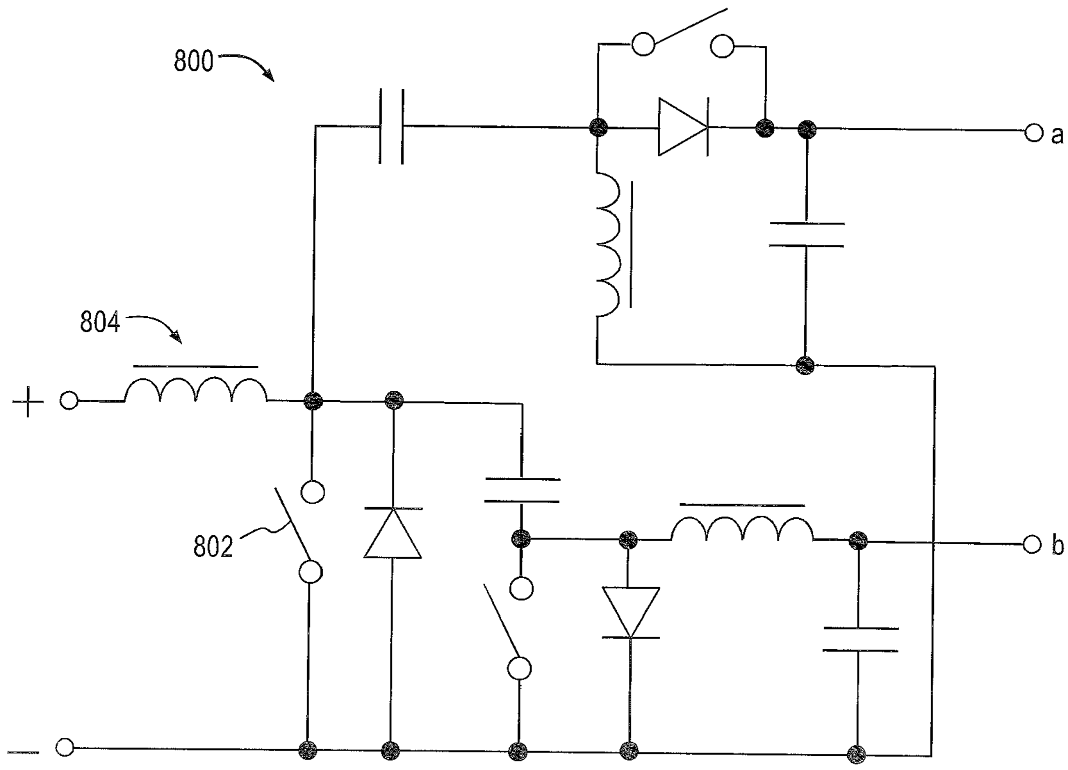



***Fig. 10***

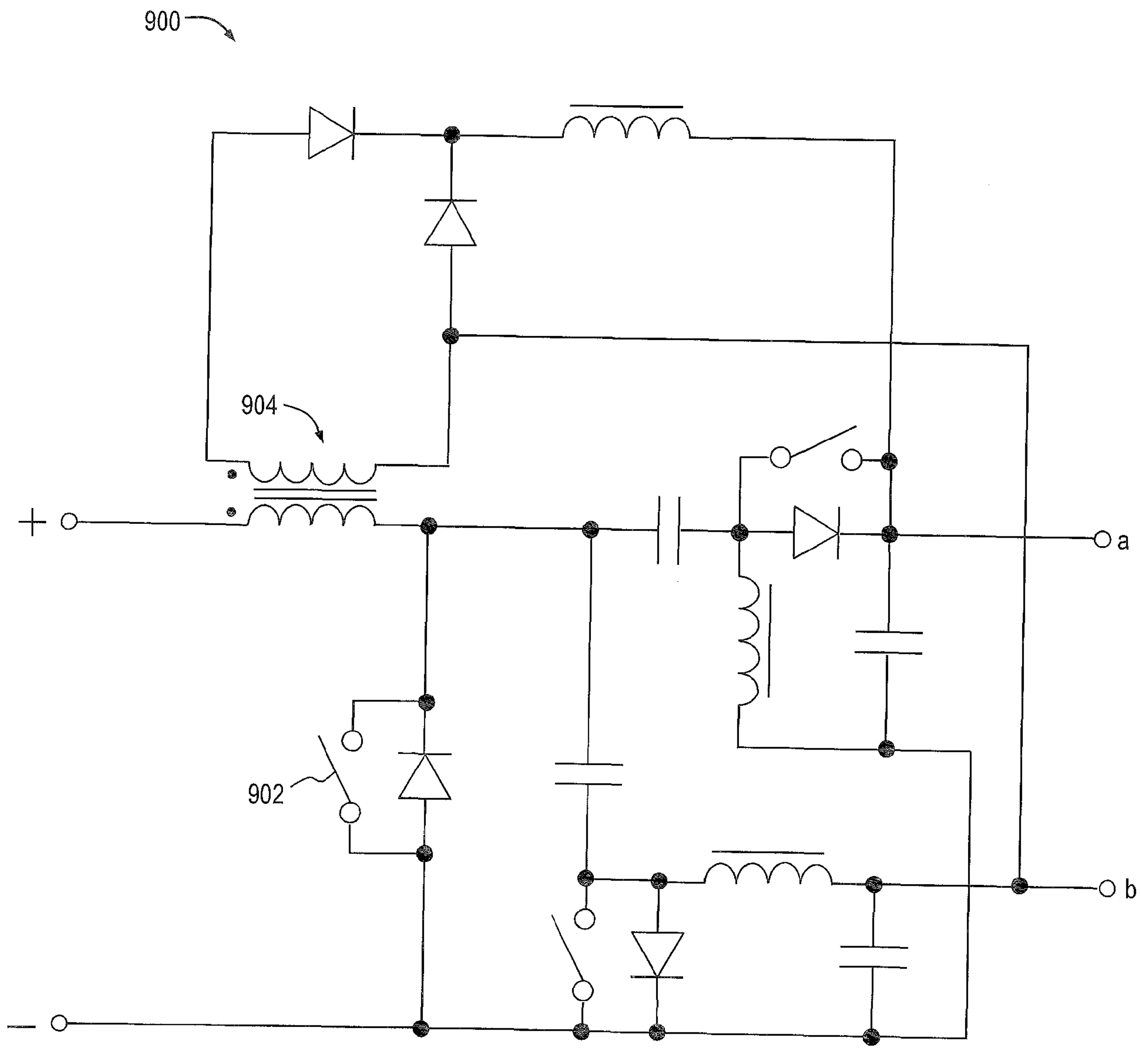
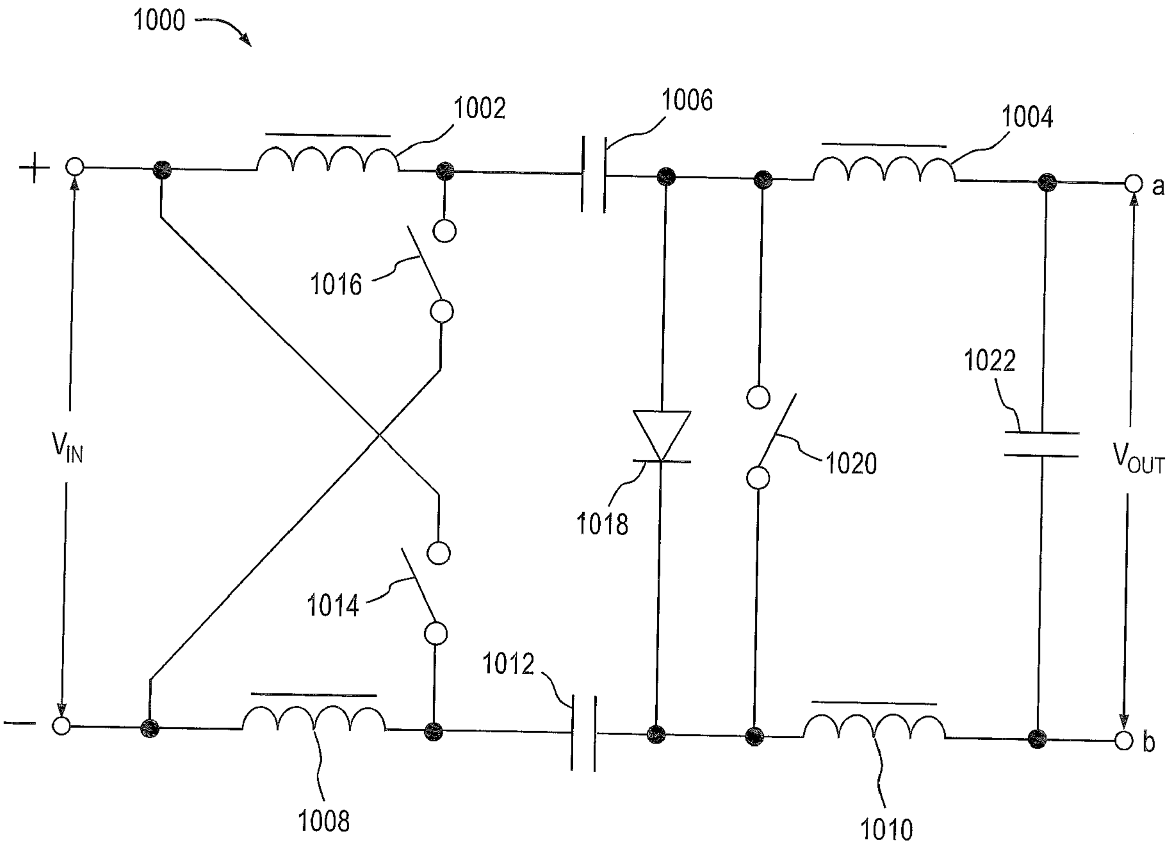



*Fig. 11*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1006
1004
+
a
1016
1022
$V_{IN}$
1020
$V_{OUT}$
1018
1014
1012
−
b
1008
1010

*Fig. 12*

## REFERENCES CITED IN THE DESCRIPTION

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### Patent documents cited in the description


- US 61785958 **[0001]**
- WO 2012146414 A2 **[0005]**