



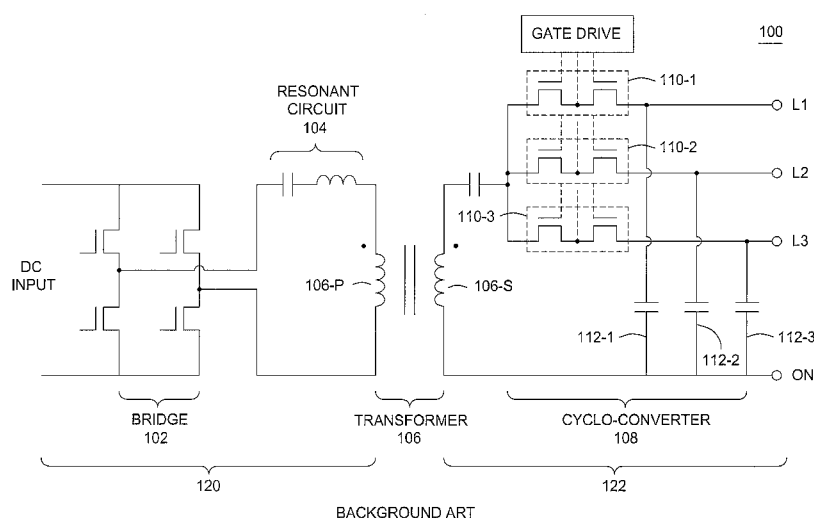
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(54) **Title:** RESONANT POWER CONVERSION CIRCUIT

BACKGROUND ART

FIG. 1

(57) **Abstract:** An apparatus and system for power conversion. In one embodiment, the apparatus comprises a transformer having a primary winding and a plurality of secondary windings; and a cyclo-converter comprising a plurality of switch pairs for converting an alternating current to an AC current, wherein each switch pair in the plurality of switch pairs (i) is coupled between two lines of an AC output and (ii) has a different secondary winding of the plurality of secondary windings coupled between its switches.

RESONANT POWER CONVERSION CIRCUIT

BACKGROUND OF THE INVENTION

Field of the Invention

[0001] Embodiments of the invention relate to power conversion and, more particularly, to a resonant power converter circuit.

Description of the Related Art

[0002] Generally, as shown in Figure 1, a DC-AC resonant power converter 100 comprises a bridge circuit 102 and resonant circuit 104 on the “DC side” 120 and a cyclo-converter circuit 108 on the “AC side” 122. As is well known in the art, the power converter circuit 100 can be used for DC to AC conversion or AC to DC conversion. Thus, the left side may be coupled to either a DC source or DC load and the right side can be coupled to an AC load or AC source.

[0003] A transformer 106 couples the two sides to one another – a primary winding 106-P is connected to the DC side and a secondary winding 106-S is connected to the AC side. A first terminal of the secondary transformer winding 106-S couples to one terminal of three bidirectional switches 110-1, 110-2, and 110-3. A second terminal of each of the three switches 110-1, 110-2, and 110-3 is connected to one of the three phases (live conductor lines L1, L2, and L3) of an AC source or load. The second terminal of the transformer secondary winding 106-S is connected to a neutral point (neutral line N) that can be connected to the AC source/load or not.

[0004] Bypass capacitors 112-1, 112-2, and 112-3 are connected from neutral line N to the respective lines L1, L2, and L3. Capacitors may be connected across each switch in the case of an LCC type resonant converter. One issue with this resonant converter circuit topology is that bidirectional switches are not commercially readily available and must be implemented with back-to-back unidirectional switches such as metal–oxide–semiconductor field-effect transistors (MOSFETs), insulated gate bipolar transistors (IGBTs), bipolar junction transistors (BJTs), and the like.

These switches have to be driven from the midpoint which swings at very high speed. In turn, such a midpoint drive creates undue drive circuit complexity as the required isolation needs to withstand very high dV/dt common mode voltages. Consequently, the drive circuit requires high isolation voltage supplies, fiber optic connections, and the like. Such complexity increases the cost of the resonant power converter.

[0005] Therefore, there is a need in the art for a resonant power converter that mitigates the foregoing problems.

SUMMARY OF THE INVENTION

[0006] Embodiments of the present invention generally relate to an apparatus and system for power conversion. In one embodiment, the apparatus comprises a transformer having a primary winding and a plurality of secondary windings; and a cyclo-converter comprising a plurality of switch pairs for converting an alternating current to a multi-phase AC current, wherein each switch pair in the plurality of switch pairs (i) is coupled between a different set of lines of an AC output and (ii) has a different secondary winding of the plurality of secondary windings coupled between its switches.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] So that the manner in which the above recited features of the present invention can be understood in detail, a more particular description of the invention, briefly summarized above, may be had by reference to embodiments, some of which are illustrated in the appended drawings. It is to be noted, however, that the appended drawings illustrate only typical embodiments of this invention and are therefore not to be considered limiting of its scope, for the invention may admit to other equally effective embodiments.

[0008] Figure 1 is a schematic diagram of a well-known resonant power converter of the background art;

[0009] Figure 2 is a schematic diagram of a power conversion circuit comprising a cyclo-converter in accordance with one or more embodiments of the present invention;

[0010] Figure 3 is a schematic diagram of a power conversion circuit comprising a cyclo-converter in accordance with one or more embodiments of the present invention;

[0011] Figure 4 is a block diagram of a system for power conversion comprising one or more embodiments of the present invention;

[0012] Figure 5 is a schematic diagram of a power conversion circuit comprising a single-phase cyclo-converter in accordance with one or more embodiments of the present invention; and

[0013] Figure 6 is a schematic diagram of a power conversion circuit comprising a split-phase cyclo-converter in accordance with one or more embodiments of the present invention.

DETAILED DESCRIPTION

[0014] Figure 2 is a schematic diagram of a power conversion circuit 200 comprising a cyclo-converter 204 in accordance with one or more embodiments of the present invention. This diagram only portrays one variation of the myriad of possible system configurations. The present invention can function in a variety of power generation environments and systems.

[0015] The DC side 120 of the conversion circuit 200 is the same as described above with respect to the background art in Figure 1. A transformer 206 couples the resonant circuit 104 to a cyclo-converter 204 having an output coupled to AC live conductor lines L1, L2, and L3 of a multi-phase AC line. The AC line may be coupled to an AC source or an AC load. In one embodiment of the invention, the secondary of the transformer 206 is divided into 3 windings 206-S1, 206-S2, and

206-S3 that are wound together (tri-filar winding). The ends of each winding are not connected together. Generally, the three windings 206-S1, 206-S2, and 206-S3 would each have the same number of turns, which may be different from the number of turns of the primary winding 106-P. The turns ratio of the secondaries 206-S1/206-S2/206-S3 to the primary 106-P depends on the ratio between input and output voltages; in some embodiments, the turns ratio may be 1:6.

[0016] The cyclo-converter 204 comprises three switch pairs 208 (having switches 208-1 and 208-2), 210 (having switches 210-1 and 210-2), and 212 (having switches 212-1 and 212-2). In one embodiment of the invention, each switch pair 208, 210, and 212 has a different secondary winding 206-S1, 206-S2, or 206-S3 coupled between drain terminals of its switches. For example, the secondary winding 206-S1 may be coupled between drain terminals of the switches 208-1 and 208-2; the secondary winding 206-S2 may be coupled between drain terminals of the switches 210-1 and 210-2; and the secondary winding 206-S3 may be coupled between drain terminals of the switches 212-1 and 212-2. The switches of each switch pair 208, 210, and 212 (which may be MOSFETs, IGBTs, BJTs and the like) may now be connected with their source terminal on a "quiet" signal, such as neutral line N (as described below with respect to Figure 3) or L1, L2 and L3. Such an arrangement eliminates the high dV/dt issues mentioned with respect to the background art.

[0017] The embodiment of Figure 2 is a "delta" configuration, where the sources of each switch pair 208, 210, and 212 are coupled to an output line L1, L2, or L3. Thus, the first pair of switches 208 couple from the transformer secondary 206-S1 to line L1 and line L2; the second pair of switches 210 couple from the transformer secondary 206-S2 to lines L2 and L3; and the third pair of switches 212 couple from the transformer secondary 206-S2 to lines L3 and L1. Additionally, an output capacitor 214-1 is coupled between line L1 and line L2; an output capacitor 214-2 is coupled between line L2 and line L3; and an output capacitor 214-3 is coupled between line L1 and line L3. The capacitances of the output capacitors 214

generally depends on the power level; in some embodiments, each of the output capacitors 214 may have a capacitance of 500 nanofarads (nF). Each switch 208-1, 208-2, 210-1, 210-2, 212-1 and 212-2, may have a capacitor 218-1, 218-2, 220-1, 220-2, 222-1 and 222-2, respectively, coupled across its drain and source terminals; such capacitors across each switch (D-S) are optional and in some embodiments may each have a capacitance of 1 nF. The output capacitors 214-1, 214-2, and 214-3 between lines L1-L2, L2-L3, and L1-L3, respectively, are not optional.

[0018] Gate terminals of each switch pair 208, 210, and 212 are coupled to a controller 230 which provides the control signals for driving the cyclo-converter 204 to perform the required DC-AC or AC-DC conversion. In some embodiments, the controller 230 may also be coupled to the bridge 102 for driving the bridge switches. In one embodiment, the controller 230 may be a control system used to switch (i.e., drive the gates of) the cyclo-converter switches 208, 210, and 212 that is the same as the control system as is used in the background art and well-known to those skilled in the art. In another embodiment, the controller 230 may comprise the control system described in commonly assigned US patent application serial number 13/342,368, titled "Method and Apparatus for Resonant Power Conversion" and filed January 3, 2012, which is herein incorporated by reference in its entirety.

[0019] Figure 3 is a schematic diagram of a power conversion circuit 300 comprising a cyclo-converter 304 in accordance with one or more embodiments of the present invention. The DC side 120 of the conversion circuit 300 is the same as described above with respect to the background art in Figure 1. A transformer 306 couples the resonant circuit 104 to a cyclo-converter 304 having an output coupled to AC live conductor lines L1, L2, and L3 of a multi-phase AC line which may be coupled to an AC source or an AC load. The cyclo-converter output is also coupled to a neutral line N, which may or may not be coupled to the AC source/load. In one embodiment of the invention, the secondary of the transformer 306 is divided into 3 windings 306-S1, 306-S2, and 306-S3 that are wound together (i.e., a tri-filar winding), the ends of each winding are not connected together, analogous to the

transformer 206 of Figure 2. Generally, the three windings 306-S1, 306-S2, and 306-S3 would each have the same number of turns, which may be different from the number of turns of the primary winding 106-P. As a result of the effective voltage for the power conversion circuit 300, the turns ratio of the secondaries 306-S1/306-S2/306-S3 to the primary 106-P would generally be smaller than the turns ratio for the power conversion circuit 200; for example, in some embodiments the turns ratio of the secondaries 306-S1/306-S2/306-S3 to the primary 106-P may be 1:5.

[0020] The cyclo-converter 304 comprises three switch pairs 308 (having switches 308-1 and 308-2), 310 (having switches 310-1 and 310-2), and 312 (having switches 312-1 and 312-2), analogous to the switch pairs 208, 210, and 212 of Figure 2. Each switch pair 308, 310, and 312 has a different secondary winding 306-S1, 306-S2, or 306-S3 coupled between drain terminals of its switches. For example, the secondary winding 306-S1 may be coupled between drain terminals of the switches 308-1 and 308-2; the secondary winding 306-S2 may be coupled between drain terminals of the switches 310-1 and 310-2; and the secondary winding 306-S3 may be coupled between drain terminals of the switches 312-1 and 312-2. The switches of each switch pair 308, 310, and 312 may be MOSFETs, IGBTs, BJTs and the like.

[0021] The embodiment of Figure 3 is a “Y” configuration, where one of the sources of each switch pair 308, 310, and 312 is coupled to an output line L1, L2, or L3, and the other source of each switch pair 308, 310, and 312 is coupled to the neutral line N. Thus, the first pair of switches 308 couple from the transformer secondary 306-S1 to line L1 and N; the second pair of switches 310 couple from the transformer secondary 306-S2 to lines L2 and N; and the third pair of switches 312 couple from the transformer secondary 306-S2 to lines L3 and N. Additionally, an output capacitor 314-1 is coupled between line L1 and N; an output capacitor 314-2 is coupled between line L2 and N; and an output capacitor 314-3 is coupled between line L3 and N. The capacitance of each of the output capacitors 314 may generally be on the order of the capacitance of each of the output capacitors 214 (e.g., 500 nF

in some embodiments), although the capacitance of each of the output capacitors 314 may be slightly larger as the Y configuration of power conversion circuit 300 would have slightly larger currents than the delta configuration of the power conversion circuit 200. Each switch 308-1, 308-2, 310-1, 310-2, 312-1 and 312-2, may have a capacitor 318-1, 318-2, 320-1, 320-2, 322-1 and 322-2, respectively, coupled across its drain and source terminals; such capacitors across each switch (D-S) are optional and in some embodiments may each have a capacitance of 1 nF. The output capacitors 314-1, 314-2, and 314-3 between L1-N, L2-N and L3-N, respectively, are not optional.

[0022] The difference in function between the delta configuration depicted in Figure 2 and the Y configuration depicted in Figure 3 is that the blocking voltage across each switch is higher for the delta configuration than for the Y configuration.

[0023] Gate terminals of each switch pair 308, 310, and 312 are coupled to a controller 330 which provides the control signals for driving the cyclo-converter 304 to perform the required DC-AC or AC-DC conversion. In some embodiments, the controller 330 may also be coupled to the bridge 102 for driving the bridge switches. In one embodiment, the controller 330 may be a control system used to switch (i.e., drive the gates of) the cyclo-converter switches 308, 310, and 312 that is the same as the control system as is used in the background art and well-known to those skilled in the art. In another embodiment, the controller 330 may comprise the control system described in previously referenced commonly assigned US patent application serial number 13/342,368, titled "Method and Apparatus for Resonant Power Conversion" and filed January 3, 2012.

[0024] Figure 4 is a block diagram of a system 400 for power conversion comprising one or more embodiments of the present invention. This diagram only portrays one variation of the myriad of possible system configurations and devices that may utilize the present invention. The present invention can be utilized in any system or device requiring a DC-AC or AC-DC converter.

[0025] The system 400 comprises a plurality of power converters 402-1, 402-2, 402-3 402-N, collectively referred to as power converters 402; a plurality of DC power sources 404-1, 404-2, 404-3....404-N, collectively referred to as DC power sources 404; a system controller 406; a bus 408; and a load center 410. The DC power sources 404 may be any suitable DC source, such as an output from a previous power conversion stage, a battery, a renewable energy source (e.g., a solar panel or photovoltaic (PV) module, a wind turbine, a hydroelectric system, or similar source of power generated from a renewable energy resource), or the like, for providing DC power. The power converters 402 may be power conversion circuits 200 comprising cyclo-converters 204, power conversion circuits 300 comprising cyclo-converters 304, or a mix thereof. In some other embodiments, the power converters may be power conversion circuits 500 comprising cyclo-converters 504 or power conversion circuits 600 comprising cyclo-converters 604.

[0026] Each power converter 402-1, 402-2, 402-3....402-N is coupled to a single DC power source 404-1, 404-2, 404-3....404-N, respectively; in some alternative embodiments, multiple DC power sources 404 may be coupled to a single power converter 402, for example a single centralized power converter 402. The power converters 402 are coupled to the system controller 406 via the bus 408. The system controller 406 is capable of communicating with the power converters 402 by wireless and/or wired communication for providing operative control of the power converters 402. The power converters 402 are further coupled to the load center 410 via the bus 408.

[0027] The power converters 402 are each capable of converting the received DC power to AC power, although in other embodiments the power converters may receive an AC input and convert the received input to a DC output. The power converters 402 couple the generated output power to the load center 410 via the bus 408. The generated power may then be distributed for use, for example to one or more appliances, and/or the generated energy may be stored for later use, for example using batteries, heated water, hydro pumping, H₂O-to-hydrogen conversion,

or the like. In some embodiments, the power converters 402 convert the DC input power to AC power that is commercial power grid compliant and couple the AC power to the commercial power grid via the load center 410. Each of the power converters 404 may or may not be coupled to a neutral line.

[0028] As previously described with respect to Figures 2 and 3, and as described further below with respect to Figures 5 and 6, the switches of the power converter cyclo-converters have their source terminals coupled to a "quiet" signal, such as neutral line (i.e., line N) or live conductor lines (i.e., L1, L2 or L3). Such an arrangement eliminates high dV/dt issues mentioned with respect to the background art of Figure 1.

[0029] Figure 5 is a schematic diagram of a power conversion circuit 500 comprising a single-phase cyclo-converter 504 in accordance with one or more embodiments of the present invention. The DC side 120 of the conversion circuit 500 is the same as described above with respect to the background art in Figure 1. A transformer 506 couples the resonant circuit 104 to a cyclo-converter 504 having an output coupled to AC live conductor lines L1 and L2 of a single-phase AC line which may be coupled to an AC source or an AC load; in some other embodiments, the cyclo-converter output may be coupled to an AC live conductor line, e.g., L1, and a neutral line N. In one embodiment of the invention, the secondary of the transformer 506 is divided into two windings 506-S1 and 506-S2 that are wound together (i.e., a bifilar winding), where the ends of each winding are not connected together. Generally, the two windings 506-S1 and 506-S2 would each have the same number of turns, which may be different from the number of turns of the primary winding 106-P. In some embodiments the turns ratio of the secondaries 506-S1/506-S2 to the primary 106-P may be 1:6.

[0030] The cyclo-converter 504 comprises two switch pairs 508 (having switches 508-1 and 508-2) and 510 (having switches 510-1 and 510-2). The switch pair 508 has the secondary winding 506-S1 coupled between drain terminals of its switches,

and the switch pair 510 has the secondary winding 506-S2 coupled between drain terminals of its switches. The switches of each switch pair 508 and 510 may be MOSFETs, IGBTs, BJTs and the like.

[0031] The sources of the switches 508-1 and 510-1 are each coupled to the output line L1, and the sources of the switches 508-2 and 510-2 are each coupled to the output line L2. Additionally, an output capacitor 514 is coupled between lines L1 and L2; in some embodiments, the capacitor 514 may be on the order 500 nF. Each switch 508-1, 508-2, 510-1, and 510-2 may have a capacitor 518-1, 518-2, 520-1, and 520-2, respectively, coupled across its drain and source terminals; such capacitors across each switch (D-S) are optional and in some embodiments may each have a capacitance of 1 nF. The output capacitor 514 across L1-L2 is not optional.

[0032] The cyclo-converter switches of each switch pair 508 and 510 are now coupled such that their source terminals are on a "quiet" signal, such line L1 or L2. Such an arrangement eliminates the high dV/dt issues mentioned with respect to the background art.

[0033] Gate terminals of each switch pair 508 and 510 are coupled to a controller 530 which provides the control signals for driving the cyclo-converter 504 to perform the required DC-AC or AC-DC conversion. In some embodiments, the controller 530 may also be coupled to the bridge 102 for driving the bridge switches. In one embodiment, the controller 530 may be a control system used to switch (i.e., drive the gates of) the cyclo-converter switches 508 and 510 that is the same as the control system as is used in the background art and well-known to those skilled in the art. In another embodiment, the controller 530 may comprise the control system described in previously referenced commonly assigned US patent application serial number 13/342,368, titled "Method and Apparatus for Resonant Power Conversion" and filed January 3, 2012.

[0034] Figure 5 is a schematic diagram of a power conversion circuit 500 comprising a single-phase cyclo-converter 504 in accordance with one or more embodiments of the present invention. The DC side 120 of the conversion circuit 500 is the same as described above with respect to the background art in Figure 1. A transformer 506 couples the resonant circuit 104 to a cyclo-converter 504 having an output coupled to AC live conductor lines L1 and L2 of a single-phase AC line which may be coupled to an AC source or an AC load; in some other embodiments, the cyclo-converter output may be coupled to an AC live conductor line, e.g., L1, and a neutral line N. In one embodiment of the invention, the secondary of the transformer 506 is divided into two windings 506-S1 and 506-S2 that are wound together (i.e., a bifilar winding), where the ends of each winding are not connected together. Generally, the two windings 506-S1 and 506-S2 would each have the same number of turns, which may be different from the number of turns of the primary winding 106-P. In some embodiments the turns ratio of the secondaries 506-S1/506-S2 to the primary 106-P may be 1:6.

[0035] The cyclo-converter 504 comprises two switch pairs 508 (having switches 508-1 and 508-2) and 510 (having switches 510-1 and 510-2). The switch pair 508 has the secondary winding 506-S1 coupled between drain terminals of its switches, and the switch pair 510 has the secondary winding 506-S2 coupled between drain terminals of its switches. The switches of each switch pair 508 and 510 may be MOSFETs, IGBTs, BJTs and the like.

[0036] The sources of the switches 508-1 and 510-1 are each coupled to the output line L1, and the sources of the switches 508-2 and 510-2 are each coupled to the output line L2. Additionally, an output capacitor 514 is coupled between lines L1 and L2; in some embodiments, the capacitor 514 may be on the order 500 nF. Each switch 508-1, 508-2, 510-1, and 510-2 may have a capacitor 518-1, 518-2, 520-1, and 520-2, respectively, coupled across its drain and source terminals; such capacitors across each switch (D-S) are optional and in some embodiments may

each have a capacitance of 1 nF. The output capacitor 514 across LI-L2 is not optional.

[0037] The cyclo-converter switches of each switch pair 508 and 510 are now coupled such that their source terminals are on a "quiet" signal, such line L1 or L2. Such an arrangement eliminates the high dV/dt issues mentioned with respect to the background art.

[0038] Gate terminals of each switch pair 508 and 510 are coupled to a controller 530 which provides the control signals for driving the cyclo-converter 504 to perform the required DC-AC or AC-DC conversion. In some embodiments, the controller 530 may also be coupled to the bridge 102 for driving the bridge switches. In one embodiment, the controller 530 may be a control system used to switch (i.e., drive the gates of) the cyclo-converter switches 508 and 510 that is the same as the control system as is used in the background art and well-known to those skilled in the art. In another embodiment, the controller 530 may comprise the control system described in previously referenced commonly assigned US patent application serial number 13/342,368, titled "Method and Apparatus for Resonant Power Conversion" and filed January 3, 2012.

[0039] Figure 6 is a schematic diagram of a power conversion circuit 600 comprising a split-phase cyclo-converter 604 in accordance with one or more embodiments of the present invention. The DC side 120 of the conversion circuit 600 is the same as described above with respect to the background art in Figure 1. A transformer 606 couples the resonant circuit 104 to a cyclo-converter 604 having an output coupled to AC live conductor lines L1 and L2 of a split-phase AC line which may be coupled to an AC source or an AC load. The cyclo-converter output is also coupled to a neutral line N, which may or may not be coupled to the AC source/load. In one embodiment of the invention, the secondary of the transformer 606 is divided into two windings 606-S1 and 606-S2 that are wound together (i.e., a bifilar winding), where the ends of each winding are not connected together.

Generally, the two windings 606-S1 and 606-S2 would each have the same number of turns, which may be different from the number of turns of the primary winding 106-P. In some embodiments the turns ratio of the secondaries 606-S1/606-S2 to the primary 106-P may be 1:6.

[0040] The cyclo-converter 604 comprises two switch pairs 608 (having switches 608-1 and 608-2) and 610 (having switches 610-1 and 610-2). The switch pair 608 has the secondary winding 606-S1 coupled between drain terminals of its switches, and the switch pair 610 has the secondary winding 606-S2 coupled between drain terminals of its switches. The switches of each switch pair 608 and 610 may be MOSFETs, IGBTs, BJTs and the like.

[0041] The source of the switch 608-1 is coupled to the output line L1, and the source of the switch 610-1 is coupled to the output line L2. The sources of the switches 608-2 and 610-2 are each coupled to the neutral line N. Additionally, an output capacitor 614-1 is coupled between lines L1 and N, and an output capacitor 614-2 is coupled between lines L2 and N. In some embodiments, the capacitors 614-1 and 614-2 may each be on the order 500 nF. Each switch 608-1, 608-2, 610-1, and 610-2 may have a capacitor 618-1, 618-2, 620-1, and 620-2, respectively, coupled across its drain and source terminals; such capacitors across each switch (D-S) are optional and in some embodiments may each have a capacitance of 1 nF. The output capacitors 614-1 and 614-2 are not optional.

[0042] The cyclo-converter switches of each switch pair 608 and 610 are now coupled such that their source terminals are on a "quiet" signal, such line L1, L2, or N. Such an arrangement eliminates the high dV/dt issues mentioned with respect to the background art.

[0043] Gate terminals of each switch pair 608 and 610 are coupled to a controller 630 which provides the control signals for driving the cyclo-converter 604 to perform the required DC-AC or AC-DC conversion. In some embodiments, the controller 630 may also be coupled to the bridge 102 for driving the bridge switches. In one

embodiment, the controller 630 may be a control system used to switch (i.e., drive the gates of) the cyclo-converter switches 608 and 610 that is the same as the control system as is used in the background art and well-known to those skilled in the art. In another embodiment, the controller 630 may comprise the control system described in previously referenced commonly assigned US patent application serial number 13/342,368, titled "Method and Apparatus for Resonant Power Conversion" and filed January 3, 2012.

[0044] The foregoing description of embodiments of the invention comprises a number of elements, devices, circuits and/or assemblies that perform various functions as described. For example, the cyclo-converter is an example of a means for converting an alternating current to a multi-phase AC current. These elements, devices, circuits, and/or assemblies are exemplary implementations of means for performing their respectively described functions.

[0045] While the foregoing is directed to embodiments of the present invention, other and further embodiments of the invention may be devised without departing from the basic scope thereof, and the scope thereof is determined by the claims that follow.

Claims:

1. An apparatus for power conversion, comprising:
a transformer having a primary winding and a plurality of secondary windings; and
a cyclo-converter comprising a plurality of switch pairs for converting an alternating current to an AC current, wherein each switch pair in the plurality of switch pairs (i) is coupled between two lines of an AC output and (ii) has a different secondary winding of the plurality of secondary windings coupled between its switches.
2. The apparatus of claim 1, wherein the plurality of secondary windings comprises a first and a second secondary winding.
3. The apparatus of claim 2, wherein the plurality of secondary windings further comprises a third secondary winding, and wherein the first, the second, and the third secondary windings are wound in a tri-filar configuration.
4. The apparatus of claim 3, wherein the plurality of switch pairs comprises first, second, and third switch pairs, and wherein the first, the second, and the third secondary windings are coupled between drain terminals of the first, the second, and the third switch pair, respectively.
5. The apparatus of claim 4, wherein the first switch pair is coupled between a first AC live conductor line and a second AC live conductor line; the second switch pair is coupled between the second AC live conductor line and a third AC live conductor line; and the third switch pair is coupled between the first AC live conductor line and the third AC live conductor line.
6. The apparatus of claim 4, wherein the first switch pair is coupled between a first AC live conductor line and a neutral line; the second switch pair is coupled between a second AC live conductor line and the neutral line; and the third switch pair is coupled between a third AC live conductor line and the neutral line.

7. The apparatus of claim 2, wherein the first and the second secondary windings are wound in a bifilar configuration.

8. The apparatus of claim 7, wherein the plurality of switch pairs comprises first and second switch pairs, and wherein the first and the second secondary windings are coupled between drain terminals of the first and the second switch pairs, respectively.

9. The apparatus of claim 8, wherein the first and the second switch pairs are coupled between a first AC live conductor line and a second AC live conductor line.

10. The apparatus of claim 8, wherein the first switch pair is coupled between a first AC live conductor line and a neutral line; and the second switch pair is coupled between a second AC live conductor line and the neutral line.

11. The apparatus of any of claims 1-8, further comprising a DC source, wherein the transformer and the cyclo-converter are part of a power converter coupled to the DC source for converting a DC current from the DC source to the AC current.

12. The apparatus of claim 11, wherein the DC source is a renewable energy source.

13. The apparatus of claim 11, wherein the DC source is a photovoltaic (PV) module.

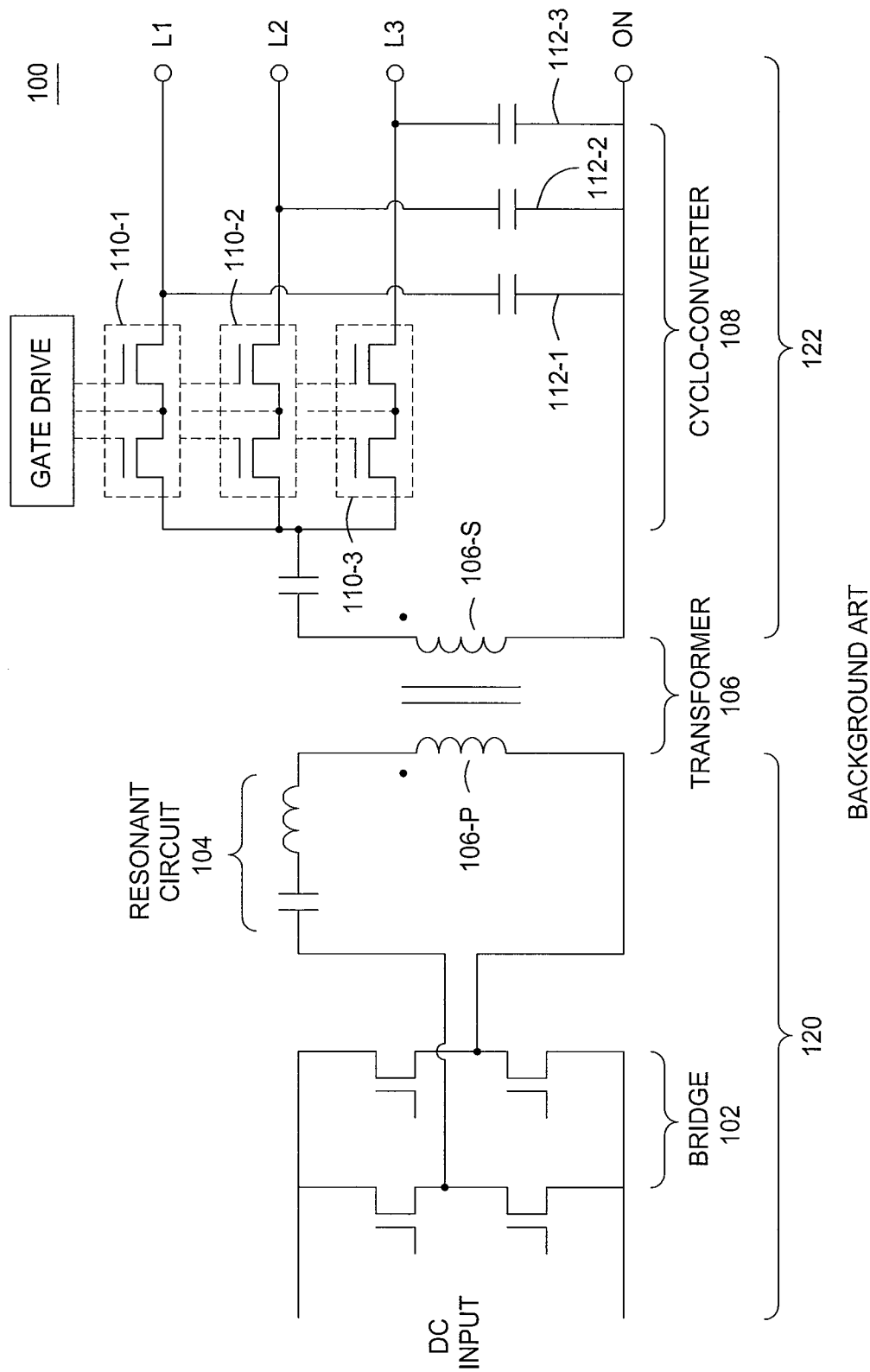


FIG. 1

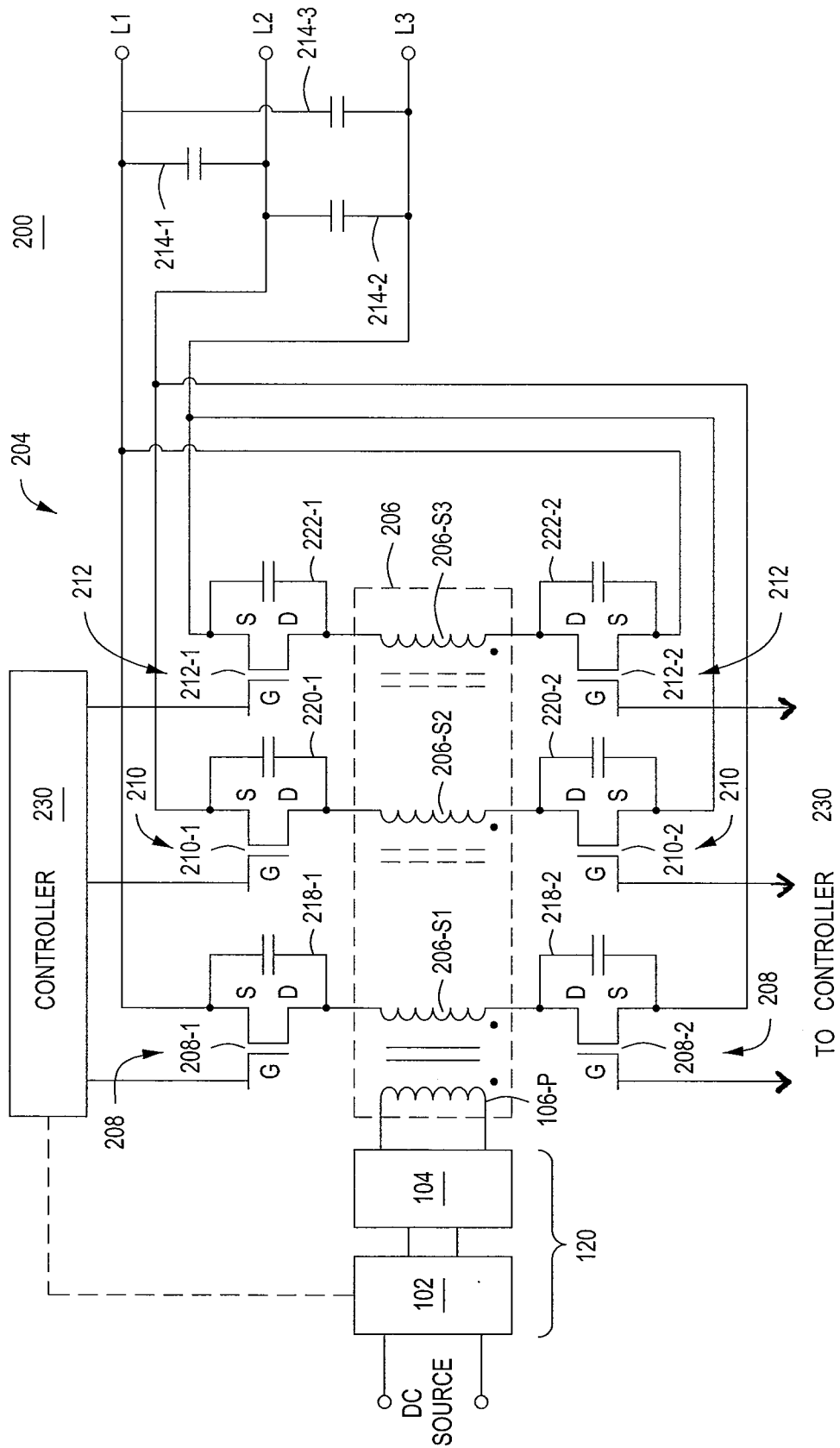


FIG. 2

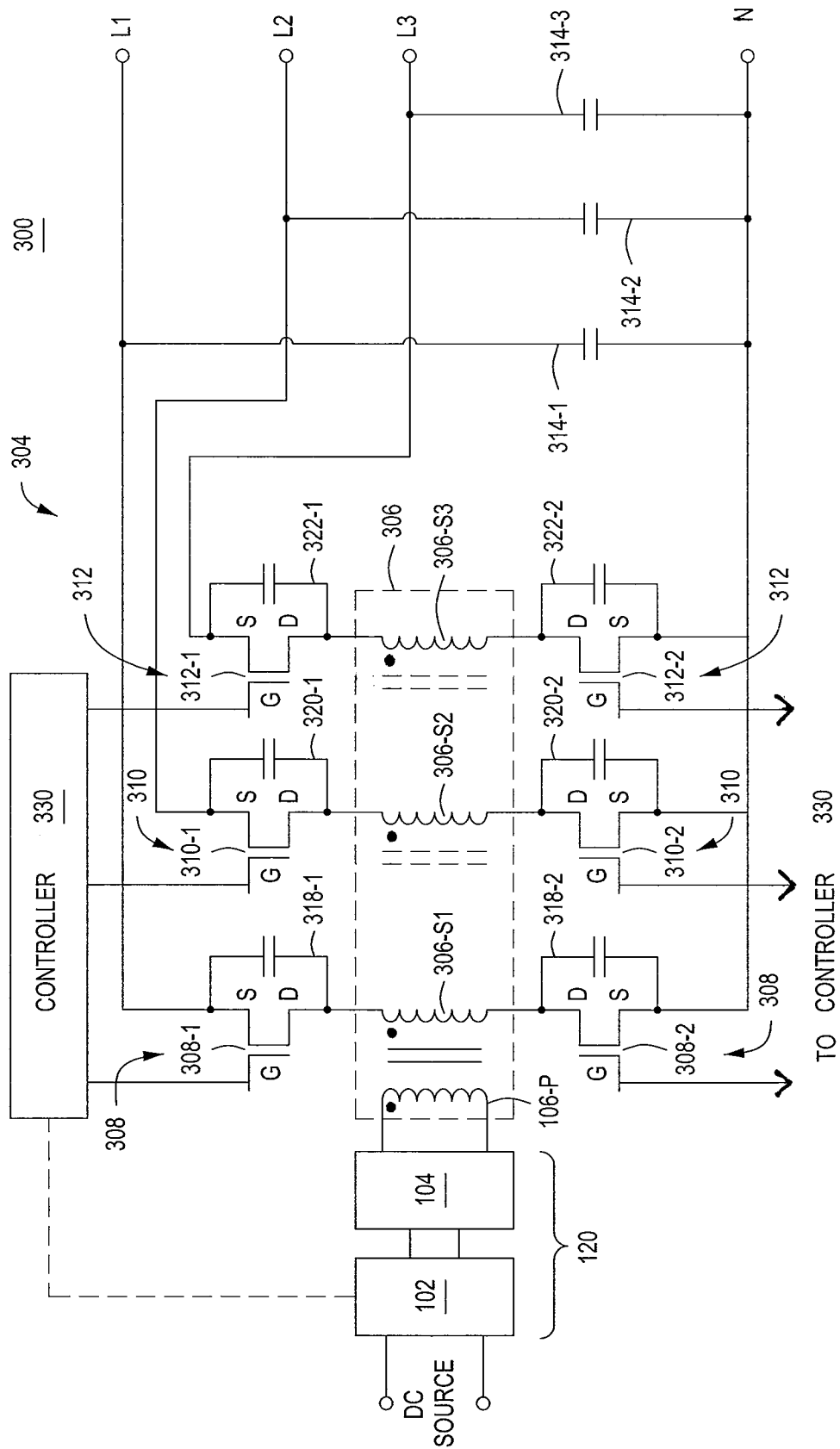


FIG. 3

400

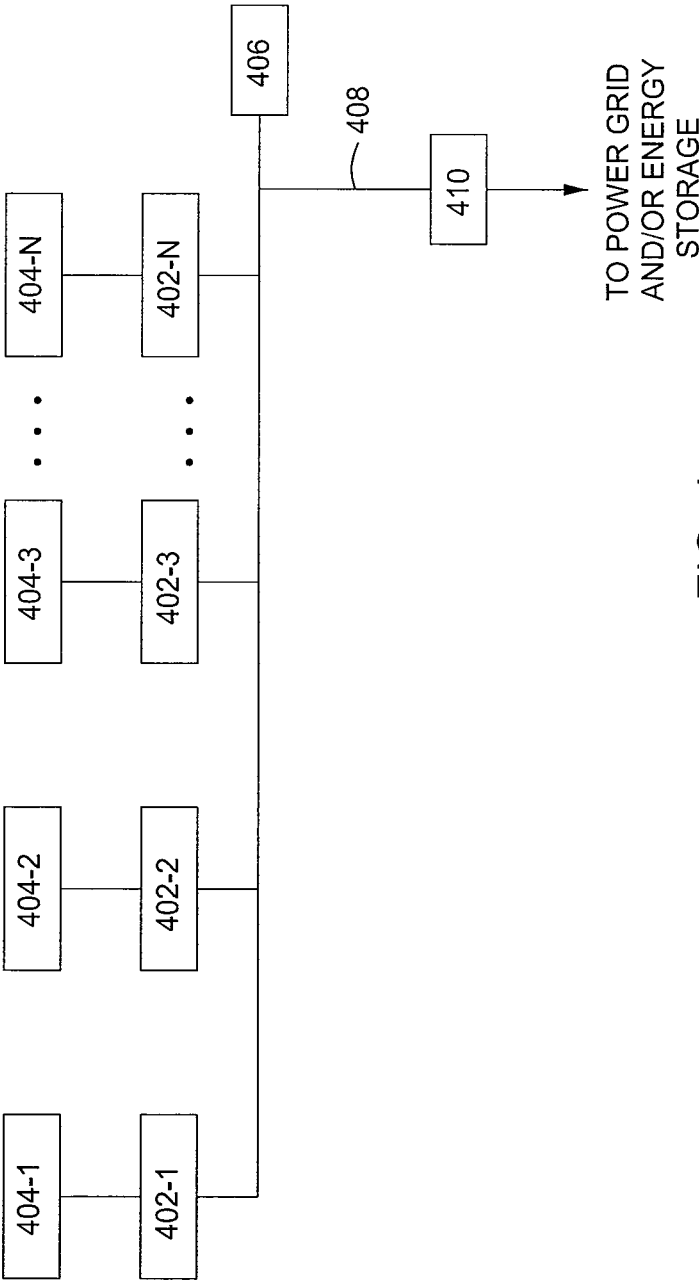


FIG. 4

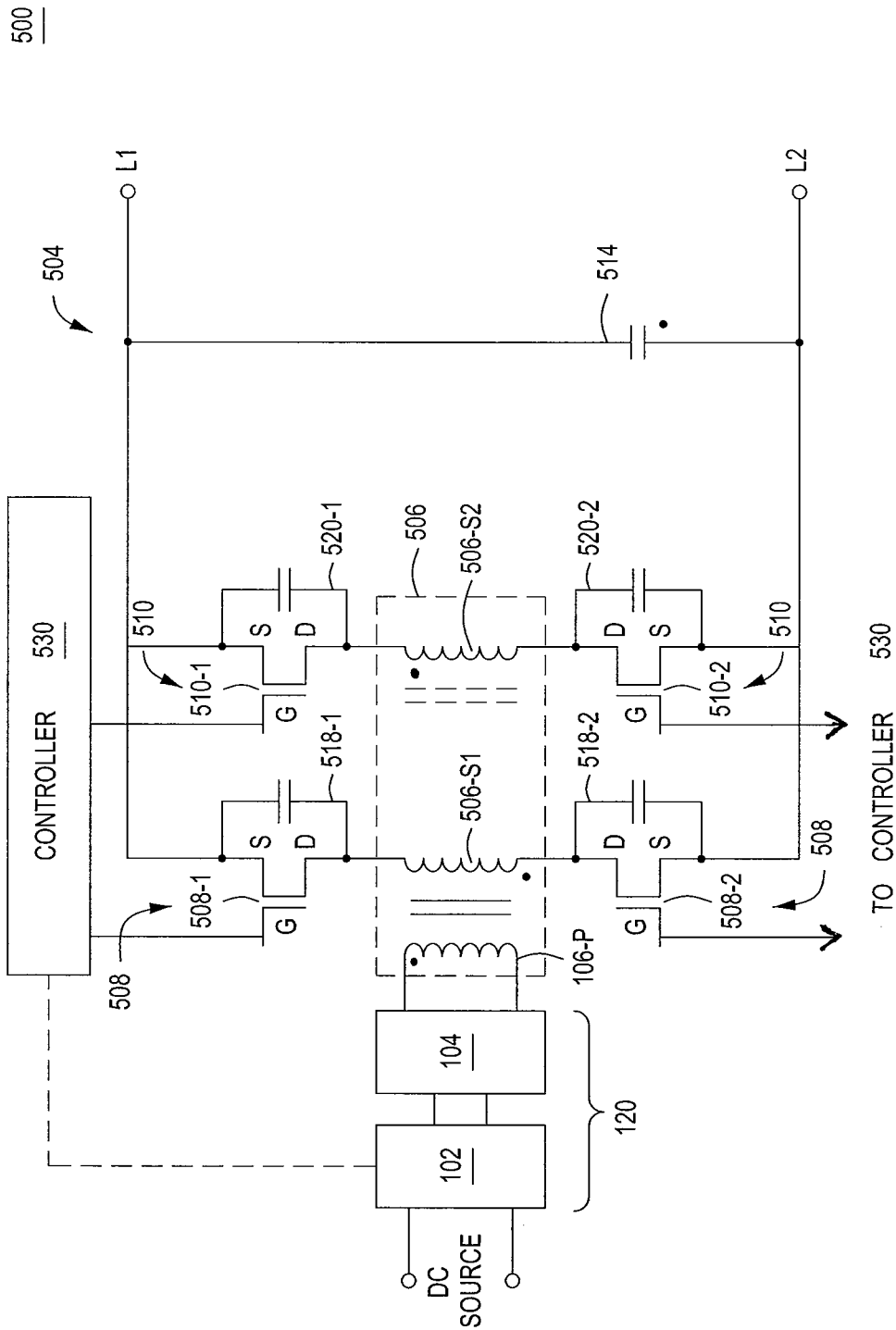


FIG. 5

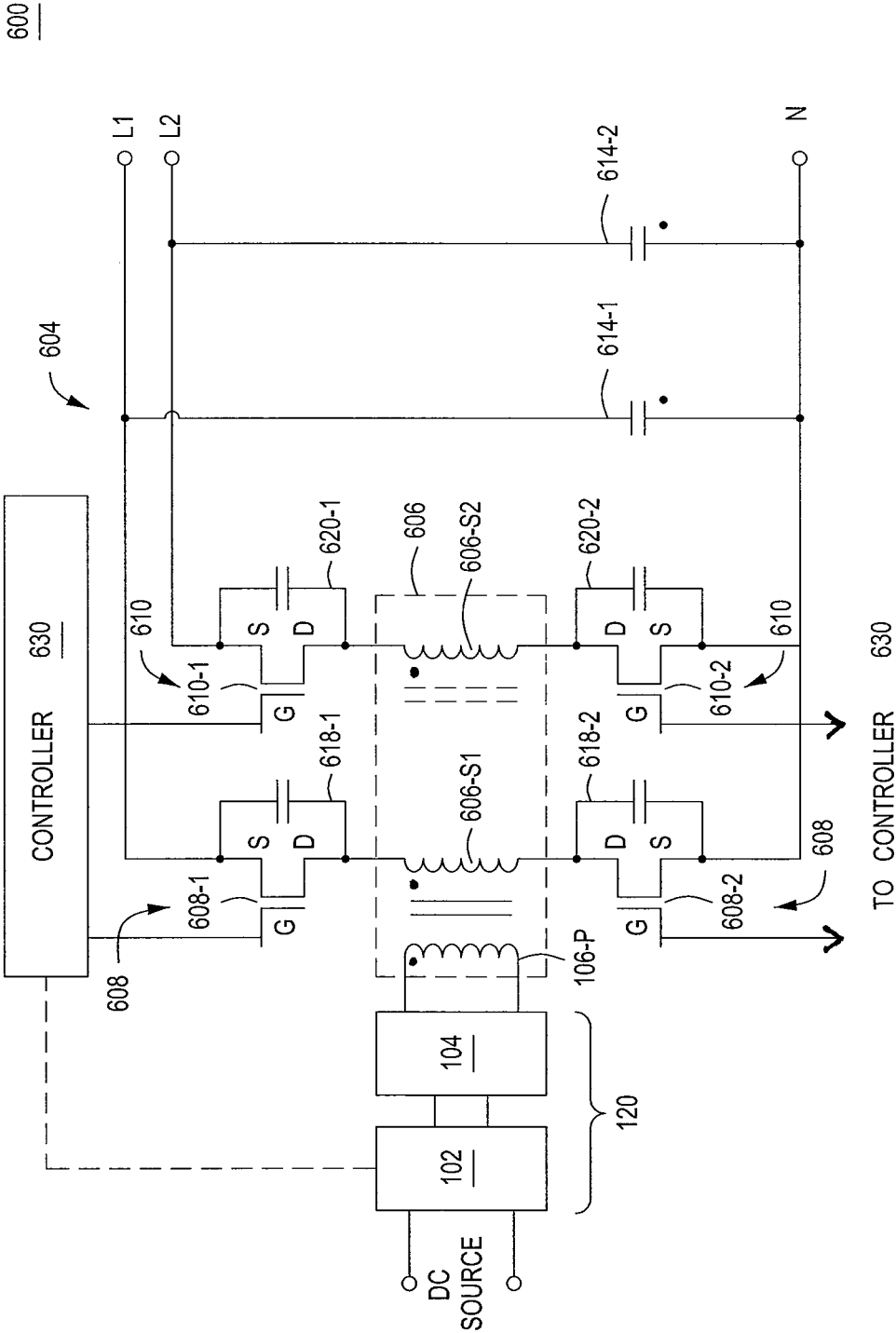


FIG. 6

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 2012/038834

A. CLASSIFICATION OF SUBJECT MATTER

*H02M 5/14 (2006.01)**H02M 5/297 (2006.01)*

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

H02M 5/14, 5/16, 5/207 5/27, 5/297, 3/335, G05F 1/00

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

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	RU 2256284 C1 (OTKRYTOEAKTSIONERNOE OBSHESTVO "IZHEVSKIY RADIOZAVOD") 10.07.2005, abstract, fig. 1, 2	1-4, 6 5, 7-10, 11-13
Y	EP 0487970 A2 (HITACHI, LTD) 03.06.1992, abstract, fig. 1, 11	5, 8, 9, 10, 11
Y	SU 1713045 A1 (NAUCHNO-PROIZVODSTVENNOE OB'EDINENIE PO RADIOELEKTRONNOI MEDITSINSKOI APPARATURE "REMA") 15.02.1992, col. 7, 2-d paragraph	7
Y	US 2007/0024257 A1 (AGENCE SPATIAL EUROPEENNE) 01.02.2007, p. 2, paragraph [0036], fig. 4	12, 13



Further documents are listed in the continuation of Box C.



See patent family annex.

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"&" document member of the same patent family

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18 July 2012 (18.07.2012)

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