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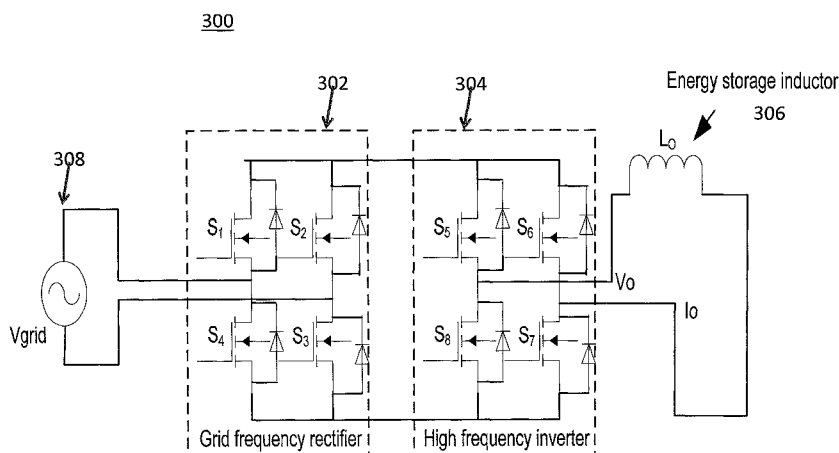


FIG. 3

(57) **Abstract:** A system for controlling reactive power may comprise a power stage circuit and a controller configured to operate the power stage circuit to provide reactive power to a utility grid. The power stage circuit may comprise a grid frequency rectifier, a high frequency inverter connected to the grid frequency rectifier, and an energy storage device connected to the high frequency inverter. The controller may be configured to operate switches in the grid frequency rectifier in synchronization with zero crossings of a grid voltage of the utility grid, and operate the high frequency inverter in duty cycle modulation.

TITLE**METHODS AND SYSTEMS FOR DYNAMIC CONTROL OF REACTIVE
POWER**

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10 Application Serial No. 61/475,315 filed on 14 April 2011, the disclosure of which is incorporated herein by reference in its entirety.

BACKGROUND

- [001] A large amount of today's electric power is generated by large-scale,
15 centralized power plants using fossil fuels, hydropower or nuclear power, and is transported over long distances to end-users. Power flows from the centralized power plants through distribution networks to consumers. The electric power from the generation station to end-users is generally delivered in form of alternating current (AC), where both current and voltages are sinusoidal, also referred to as AC
20 systems. In AC systems, power is measured as the rate of flow of energy past a given point. If the end-users load is purely resistive, only real power is transferred, as both the voltage and the current are in phase. If the end-users load is purely reactive (capacitor and inductor), the voltage and the current are 90 degrees out of phase and there is no net transfer of energy to the load.

- 25 [002] Practical end-user loads have resistance, inductance, and capacitance, so both real and reactive power flow to the end-user loads. The inductive and capacitive properties of the end-user load cause the current to change phase with respect to voltage: capacitance tending the current to lead the voltage in phase, and inductance to lag it. For transmitting the same amount of real power, the AC system
30 with higher phase difference between the current and the voltage will have higher circulating current, hence higher losses. Moreover, the higher circulating currents

require higher rated equipment (conductors, transformers, etc.) or can cause damage to the equipment due to overcurrent.

[003] Hence in AC systems, to transfer maximum amount of energy, and to increase the efficiency and stability, the phase difference between the current and the voltage should be minimal. The phase difference between the current and the voltage is controlled by absorbing or delivering reactive power in the electric power systems. The control of reactive power in the electric power system is referred to as VAR support. These VAR compensators are generally located in a distribution substation or on feeders closer to the distribution substation. These VAR compensators offer minimal or no protection to transformers or other equipment's located near the loads. Moreover, the present day VAR compensators are stand-alone.

SUMMARY

[004] Consistent with embodiments of the present invention, systems and methods are disclosed for control of reactive power in an electric power system. A system for controlling reactive power may comprise a power stage circuit and a controller configured to operate the power stage circuit to provide reactive power to a utility grid. The power stage circuit may comprise a grid frequency rectifier, a high frequency inverter connected to the grid frequency rectifier, and an energy storage device connected to the high frequency inverter. The controller may be configured to operate switches in the grid frequency rectifier in synchronization with zero crossings of a grid voltage of the utility grid, and operate the high frequency inverter in one of the following: duty cycle modulation and frequency modulation.

[005] It is to be understood that both the forgoing general description and the following detailed description are examples and explanatory only, and should not be considered to restrict the invention's scope, as described and claimed. Further, features and/or variations may be provided in addition to those set forth herein. For example, embodiments of the invention may be directed to various feature combinations and sub-combinations described in the detailed description.

BRIEF DESCRIPTION OF THE DRAWINGS

[006] The accompanying drawings, which are incorporated in and constitute a part of this disclosure, illustrate various embodiments of the present invention. In the drawings:

5 [007] FIG. 1 shows a prior art SVC topology based VAR compensator;

[008] FIG. 2 shows a prior art STATCOM topology based VAR compensator;

[009] FIG. 3 shows a power stage circuit;

[0010] FIG. 4 shows a power stage circuit in a first mode;

10 [0011] FIG. 5 shows a power stage circuit in a second mode;

[0012] FIG. 6 shows a power stage circuit in a third mode;

[0013] FIG. 7 shows a power stage circuit in a fourth mode; and

[0014] FIG. 8 is a block diagram showing a control strategy.

15 DETAILED DESCRIPTION

[0015] The following detailed description refers to the accompanying drawings. Wherever possible, the same reference numbers are used in the drawings and the following description to refer to the same or similar elements. While embodiments of the invention may be described, modifications, adaptations, and other implementations are possible. For example, substitutions, additions, or modifications may be made to the elements illustrated in the drawings, and the methods described herein may be modified by substituting, reordering, or adding stages to the disclosed methods. Accordingly, the following detailed description does not limit the invention. Instead, the proper scope of the invention is defined by the appended claims.

[0016] Embodiments of the invention may provide a system and a method for controlling reactive power in an electric power system by providing distributed VAR compensator. The reactive power may be controlled by absorbing or delivering reactive power in the electric power system through the distributed VAR compensator. There are two different known topologies for VAR compensators, Static VAR Compensator (SVC) topology and Static Synchronous Compensator (STATCOM) topology.

[0017] FIG. 1 shows a prior art SVC topology based VAR compensator. The SVC topology based VAR compensator of FIG. 1 includes capacitors C_1, C_2, C_n and inductors L_1, L_2, L_3, L_n as energy storage devices. The SVC topology based VAR compensator of FIG. 1, further includes thyristors T_1, T_2, T_3, T_n as switches to control the flow of energy from the energy storage devices to the electric power system. One of the drawbacks of this SVC topology based VAR compensator is that it offers VAR capability in steps of impedances. Although the step size of impedances can be reduced by adding more capacitors, inductors and thyristors, adding these elements increases complexity. Another drawback of the SVC topology based VAR compensator is that it injects line frequency harmonics in the electric power system. Since the thyristors T_1, T_2, T_3 , and T_n are operated during the line voltage, the SVC topology based VAR compensator generate line frequency harmonics. Filters are required to suppress the generated line frequency harmonics, which further increases the complexity. Moreover, the energy storage with numerous capacitors and inductors makes the SVC topology based VAR compensator very bulky.

[0018] FIG. 2 shows a prior art voltage source STATCOM topology based VAR compensator. The voltage source STATCOM topology based VAR compensator is used for single phase VAR control. As depicted in FIG. 2, the voltage source STATCOM topology based VAR compensator includes a pulse width modulation (PWM) inverter with an electrolytic capacitor. The electrolytic capacitor is used as an energy storage device and the PWM inverter is used to control flow of energy from the electrolytic capacitor to the electric power system. Although, voltage source STATCOM topology based VAR compensator has lesser number of power devices, the switching losses are high compared to the SVC topology based VAR compensator. Moreover, the voltage source STATCOM topology based VAR compensators have lesser reliability due to use of capacitive storage.

[0019] Consistent with embodiments of the present invention, FIG. 3 shows a power stage circuit 300 that may be used for controlling reactive power in a utility grid. As shown in FIG.3, power stage circuit 300 may comprise a grid frequency rectifier 302, a high frequency inverter 304, and an energy storage device 306. A first end of the grid frequency rectifier 302 may be connected to utility grid 308. A

first end of the high frequency inverter 304 may be connected to a second end of grid frequency rectifier 304. A second end of the high frequency inverter 304 may be connected to the energy storage device 306.

[0020] Consistent with embodiments of the present invention, grid frequency
5 rectifier 302 and high frequency inverter 304 may be configured to regulate an amount of reactive power flowing in or out of energy storage device 306. Grid frequency rectifier 302 may be configured to convert an alternating current (AC), which periodically reverses direction, from the utility grid 308, to a direct current (DC), which flows in only one direction. As an example, grid frequency rectifier
10 304 may be a full wave rectifier and may convert the whole of the input waveform to a waveform of constant polarity (positive or negative) at its output.

[0021] Grid frequency rectifier 302 may include four switching elements S_1 , S_2 , S_3 and S_4 , also referred to as switches. The switches S_1 , S_2 , S_3 and S_4 of grid frequency rectifier 302 may be switched in synchronization with zero crossing of a
15 grid voltage (V_{grid}) of the utility grid 308. The output of grid frequency rectifier 302 may be a rectified sinusoid DC having a frequency two times of the grid voltage frequency. The switches S_1 , S_2 , S_3 and S_4 may be, for example, Metal Oxide Semiconductor Field Effect Transistor (MOSFET), Insulated Gate Bipolar
20 Transistor (IGBT), diodes, mercury arc valves, or other silicon based semiconductor switches. In one example, switches S_1 , S_2 , S_3 and S_4 may be arranged to form a bridge rectifier.

[0022] The output of grid frequency rectifier 302 may be coupled to high frequency inverter 304. High frequency inverter 304 may be configured to convert the DC output from grid frequency rectifier 302 to an AC with a predetermined
25 frequency. As shown in FIG. 3, high frequency inverter 304 may include four switching elements S_5 , S_6 , S_7 and S_8 , also referred to as switches. The switches S_5 , S_6 , S_7 and S_8 may, for example, be Metal Oxide Semiconductor Field Effect Transistor (MOSFET), Insulated Gate Bipolar Transistor (IGBT), diodes, mercury arc valves, or other silicon based semiconductor switches.

30 [0023] Consistent with embodiments of the present invention, the switches S_5 , S_6 , S_7 and S_8 of high frequency inverter 304, may be operated at a predetermined switching frequency to control an amount of reactive power flowing in and out of energy storage device 306. The amount of reactive power may be controlled by

controlling an amount of current flowing through energy storage device 306. The amount of current flowing through energy storage device 306 may be controlled by controlling a switching sequence and frequency of switching of the switches of high frequency inverter 304. As an example, the switches S_5 , S_6 , S_7 and S_8 may be
5 switched on and off at a switching frequency significantly higher (for example, ten times) than the frequency of the grid voltage (V_{grid}).

[0024] High frequency inverter 304 may be a bidirectional inverter, and the converted AC at the output of high frequency inverter 304 may be at any desired voltage and frequency with the use of appropriate switching of the switches S_5 , S_6 ,
10 S_7 and S_8 .

[0025] Consistent with embodiments of the present invention, energy storage device 306 may be a magnetic storage device. The magnetic storage device may increase the reliability of power stage circuit 300. As an example, the energy storage device 306 may be an inductor. In one embodiment, the inductor may also
15 be operated as a capacitor with a suitable duty cycle modulation of high frequency inverter 304. As an example, a suitable duty cycle modulation may allow the inductor to act functionally as capacitor drawing current which has positive phase angle with respect to the grid voltage (V_{grid})

[0026] FIG. 4 shows a power stage circuit 300's operation in a first mode
20 (i.e. mode 1). In the first mode of operation, the grid voltage (V_{grid}) is positive and the voltage (V_o) across the energy storage device 306 is also positive. Since the grid voltage (V_{grid}) is positive, the switches S_1 and S_3 of the grid frequency rectifier 302 may be switched ON. Since the voltage across the energy storage device 306 is also positive, the switches S_5 and S_7 of the high frequency inverter 304 may be switched
25 ON. In the first mode, the flow of energy may be bidirectional, i.e. from the utility grid 308 to the energy storage device 306 and from the energy storage device 306 to the utility grid 308.

[0027] FIG. 5 shows power stage circuit 300 in a second mode (i.e. mode 2) of operation. In the second mode of operation, the grid voltage (V_{grid}) is positive
30 and the voltage (V_o) across energy storage device 306 is negative. Since the grid voltage (V_{grid}) is positive, the switches S_1 and S_3 of grid frequency rectifier 302 may be switched ON. Since the voltage (V_o) across energy storage device 306 is negative, the switches S_6 and S_8 of high frequency inverter 304 may be switched

ON. The flow of energy in the second mode of operation may also be bidirectional, i.e. from utility grid 308 to energy storage device 306 and from energy storage device 306 to utility grid 308.

[0028] FIG. 6 shows power stage circuit 300 in a third mode (i.e. mode 3) of operation. In the third mode of operation, the grid voltage (V_{grid}) is negative and the voltage (V_o) across energy storage device 306 is positive. Since the grid voltage (V_{grid}) is negative, the switches S_2 and S_4 of grid frequency rectifier 302 may be switched ON. Since the voltage (V_o) across energy storage device 306 is positive, the switches S_5 and S_7 of high frequency inverter 304 may be switched ON. The flow of energy in the third mode of operation may also be bidirectional i.e. from utility grid 308 to energy storage device 306 and from energy storage device 306 to the utility grid 308.

[0029] FIG. 7 shows a power stage circuit 300's in a fourth mode (i.e. mode 4) of operation. In the fourth mode of operation the grid voltage (V_{grid}) is negative and the voltage (V_o) across the energy storage device 306 is also negative. Since the grid voltage (V_{grid}) is negative, the switches S_2 and S_4 of the grid frequency rectifier 302 may be switched ON. Since the voltage (V_o) across the energy storage device 306 is also negative, the switches S_6 and S_8 of the high frequency inverter 304 may be switched ON. The flow of energy in the fourth mode of operation may also be bidirectional, i.e. from the utility grid 308 to the energy storage device 306 and from the energy storage device 306 to the utility grid 308.

[0030] Consistent with embodiments of the present invention, power stage circuit 300 may be operated, for example, using duty cycle modulation. A control strategy diagram 800 for active and reactive power generation is shown in FIG. 8. As illustrated in FIG. 8, a loop may be utilized to control operations of the high frequency inverter 304.

[0031] The grid frequency rectifier 302 switches are operated in synchronization with the grid voltage (V_{grid}) by toggling them ON and OFF at the grid voltage frequency. The switches of grid frequency rectifier 302 may be silicon based semiconductor switches and may require gating signals to operate. The gating signals may be generated using first gate driver 812. First gate driver 812 may generate the gating signals based on a trigger. The trigger for first gate driver 812 may be provided by zero crossing detector 810.

[0032] In one example, voltage sensors (not shown in FIG. 8) may sense an instantaneous voltage of utility grid 308. The sensed grid voltage (V_{grid}) may be used as an input for zero crossing detector 810. Zero crossing detector 810 may be configured to detect zero crossings of the grid voltage (V_{grid}) and generate triggers
5 corresponding to each zero crossing of the grid voltage. The triggers generated by zero crossing detector 810 may be sent to first gate driver 812. First gate driver 812 may generate four gating signals which may be applied to gates of the switches S_1 , S_2 , S_3 , and S_4 .

[0033] The high frequency inverter control loop may be configured to
10 control the instantaneous output current of the high frequency inverter (e.g. high frequency inverter 304). The high frequency inverter control loop may include a phase locked loop (PLL) circuit 814, a multiplier 818, a VAR controller 816, an input current regulator 820, a modulator 822, and a second gate driver 824.

[0034] Consistent with embodiments of the present invention, the
15 instantaneous output current of high frequency inverter 304 may be controlled by operating the switches of the inverter 304. The switches of high frequency inverter 304 may be silicon based semiconductor switches and may require gating signals to operate. The gating signals for the switches of high frequency inverter 304 are derived from second gate driver 824. Second gate driver 824 may generate the
20 gating signals based on a trigger provided by modulator 822. Modulator 824 may generate the triggers based on a duty cycle.

[0035] In one example, the sensed grid voltage (V_{grid}) may be used as an input to phase locked loop (PLL) circuit 814. PLL circuit 814 may generate two output signals. A first signal generated by PLL circuit 814 may be in phase with the
25 grid voltage (V_{grid}). A second signal generated by PLL circuit 814 may have 90 degree phase shift with respect to the grid voltage (V_{grid}).

[0036] VAR controller 816 may determine a magnitude and a phase of the required reactive power. The output from VAR controller 816 and PLL circuit 814 may be sent as inputs to multiplier 818. Multiplier 818, may multiply the inputs to
30 generate a reference current (I_{ref}) as the output. The output from multiplier 818 may be sent as an input to input current regulator 820.

[0037] Another input to input current regulator 820 may be the grid current (I_{sens}) sensed by the current sensor. Input current regulator 820 may be configured to

maintain the waveform and the magnitude of input currents. The output from the input current regulator 820 may be used as an input for modulator 822. Modulator 822, based on the output from input current regulator 822, may compute a duty cycle as an output. The computed duty cycle, the output from modulator 822, may be
 5 used as an input for second gate driver 824.

[0038] Consistent with embodiments of the present invention, the duty cycle for high frequency inverter 304 may be calculated based on a desired amount of reactive power to be delivered or absorbed in utility grid 308. The desired amount of reactive power may be calculated based on the sensed instantaneous voltage of
 10 the utility grid (V_{grid}) and a rating of the energy storage device (L).

[0039] A reactive component of the sensed instantaneous voltage of the utility grid may be represented as:

$$V_{grid} = V_m \sin(\omega t) \dots\dots\dots (1)$$

wherein V_m is magnitude of the grid voltage and ω is frequency of the grid voltage.

15 [0040] The desired reactive component of the grid current may be represented as:

$$I_{grid} = I_m \sin(\omega t + \phi) \dots\dots\dots (2)$$

wherein I_m is magnitude of the desired current, ω is the frequency of the grid voltage and ϕ is phase difference.

20 [0041] The desired amount of reactive power may be calculated using equations (1) and (2) as:

$$Input\ VAR = V_{grid} \times I_{grid} \dots\dots\dots (3)$$

[0042] Using equation (3), the required reactive energy which needs to be absorbed or delivered to the utility grid may be calculated as:

$$25 \quad Energy = \int Input\ VAR \dots\dots\dots (4)$$

[0043] The energy required (as represented by equation (4)) may be absorbed or delivered by energy storage device 306. Since energy storage device 306 is a magnetic storage device, the required energy of equation 4 may be absorbed or delivered by controlling current flowing through energy storage device 306. The
 30 current flowing through energy storage device 306 may also be referred to as output current. The output current in energy storage device 306 for absorbing or delivering the required energy, may be calculated as:

$$I_o = \sqrt{\frac{2}{L} \times \text{Energy}} \dots\dots(5)$$

wherein L is the inductance of energy storage device 306 (inductance).

[0044] The output current of energy storage device 306 is regulated by regulating the duty cycle of high frequency inverter 304. The duty cycle for high frequency inverter 304 to achieve the desired output current may be calculated by using equation (5) and the desired value of the grid current (I_{grid}) as:

$$\text{duty cycle} = \frac{I_{\text{grid}}}{I_o} \dots\dots (6)$$

[0045] Consistent with embodiments of the present invention, the equation (6) may show that the amount of energy to be delivered or absorb from the utility grid may be regulated by regulating the duty cycle of high frequency inverter 306. Moreover, the amount of energy can be dynamically modified based on an instantaneous value of the grid voltage.

[0046] Controlling reactive power in a utility grid using distributed VAR compensators may allow maintaining a desired level of phase difference between the voltage and the current in the utility grid. Further, using magnetic storage may provide the VAR compensators much higher reliability than that of capacitive storage. Moreover, controlling the reactive power may allow maintaining a stable voltage and a stable current throughout the utility grid. The distribution of the VAR compensators may help in avoiding reliance on a centralized VAR compensation that may require big reactive element, and may generate line frequency harmonics. Further, avoiding reliance on the centralized VAR support may eliminate possibility of a single point of failure. The distributed VAR compensators, using separate VAR units, by providing VAR support at the point of load may increase the overall performance of the utility grid, and may decrease the losses and voltage fluctuations for the customers.

[0047] Embodiments of the invention may be practiced in an electrical circuit comprising discrete electronic elements, packaged or integrated electronic chips containing logic gates, a circuit utilizing a microprocessor, or on a single chip containing electronic elements or microprocessors. Embodiments of the invention may also be practiced using other technologies capable of performing logical operations such as, for example, AND, OR, and NOT, including but not limited to

mechanical, optical, fluidic, and quantum technologies. In addition, embodiments of the invention may be practiced within a general purpose computer or in any other circuits or systems.

[0048] Embodiments of the invention, for example, may be implemented as
5 a computer process (method), a computing system, or as an article of manufacture, such as a computer program product or computer readable media. The computer program product may be a computer storage media readable by a computer system and encoding a computer program of instructions for executing a computer process. The computer program product may also be a propagated signal on a carrier readable
10 by a computing system and encoding a computer program of instructions for executing a computer process. Accordingly, the present invention may be embodied in hardware and/or in software (including firmware, resident software, micro-code, etc.). In other words, embodiments of the present invention may take the form of a computer program product on a computer-usable or computer-readable storage
15 medium having computer-usable or computer-readable program code embodied in the medium for use by or in connection with an instruction execution system. A computer-usable or computer-readable medium may be any medium that can contain, store, communicate, propagate, or transport the program for use by or in connection with the instruction execution system, apparatus, or device.

20 [0049] The computer-usable or computer-readable medium may be, for example but not limited to, an electronic, magnetic, optical, electromagnetic, infrared, or semiconductor system, apparatus, device, or propagation medium. More specific computer-readable medium examples (a non-exhaustive list), the computer-readable medium may include the following: an electrical connection having one or
25 more wires, a portable computer diskette, a random access memory (RAM), a read-only memory (ROM), an erasable programmable read-only memory (EPROM or Flash memory), an optical fiber, and a portable compact disc read-only memory (CD-ROM). Note that the computer-usable or computer-readable medium could even be paper or another suitable medium upon which the program is printed, as the
30 program can be electronically captured, via, for instance, optical scanning of the paper or other medium, then compiled, interpreted, or otherwise processed in a suitable manner, if necessary, and then stored in a computer memory.

[0050] Embodiments of the present invention, for example, are described above with reference to block diagrams and/or operational illustrations of methods, systems, and computer program products according to embodiments of the invention. The functions/acts noted in the blocks may occur out of the order as shown in any flowchart. For example, two blocks shown in succession may in fact be executed substantially concurrently or the blocks may sometimes be executed in the reverse order, depending upon the functionality/acts involved.

[0051] While the specification includes examples, the invention's scope is indicated by the following claims. Furthermore, while the specification has been described in language specific to structural features and/or methodological acts, the claims are not limited to the features or acts described above. Rather, the specific features and acts described above are disclosed as example for embodiments of the invention.

WHAT IS CLAIMED IS:

1. A system for controlling reactive power, the system comprising:
a power stage circuit comprising,
a grid frequency rectifier configured to connect to a utility grid,
5 a high frequency inverter connected to the grid frequency rectifier,
and
an energy storage device connected to the high frequency inverter;
and
a controller configured to operate the power stage circuit to provide reactive
10 power to the utility grid, the controller being configured to,
switch switches in the grid frequency rectifier in synchronization with
zero crossings of a grid voltage of the utility grid, and
operate the high frequency inverter in duty cycle modulation.
- 15 2. The system of claim 1, wherein switches in the high frequency
inverter are switched on and off at a switching frequency equal to or more than ten
times of grid voltage frequency.
3. The system of claim 1, wherein the high frequency inverter is
20 operated to control energy flowing in and out of the energy storage device.
4. The system of claim 1, wherein the duty cycle of the high frequency
converter is calculated based on instantaneous measurement of power grid current
and an amount of reactive power required in the utility grid.
25
5. The system of claim 1, wherein the energy storage device is a
magnetic storage device.
6. The system of claim 1, wherein the energy storage device is an
30 inductor.
7. The system of claim 1, wherein the grid frequency rectifier and the
high frequency inverter each comprises four switches.

8. The system of claim 1, wherein the switches in the grid frequency rectifier are metal oxide semiconductor field effect transistor (MOSFETs) or insulated gate bipolar transistor (IGBT).

- 5 9. A method for controlling reactive power, the method comprising:
receiving an instantaneous measurement of a grid voltage (V_{grid}) and a grid
current (I_{grid}) of a utility grid;
calculating an instantaneous value of a reference current (I_{ref}) based on the
received instantaneous measurement of the grid voltage (V_{grid}) and the grid current
10 (I_{grid});
creating a first control signal based on the received instantaneous
measurement of the grid voltage (V_{grid}) for operating switches of a grid frequency
rectifier connected to the utility grid;
creating a second control signal based on the calculated instantaneous value
15 of the current reference (I_{ref}) for operating switches of a high frequency inverter
connected to the grid frequency rectifier; and
regulating, based on the created first control signal and the second control
signal, current flowing through an energy storage device connected to the high
frequency inverter, to control an amount of reactive power in the utility grid.
20
10. The method of claim 9, wherein operating switches of a high
frequency inverter comprises operating the high frequency inverter in duty cycle
modulation.
- 25 11. The method of claim 10, wherein operating the high frequency
inverter in duty cycle modulation comprises determining a duty cycle wherein the
duty cycle is determined based on an amount of reactive power required in the
power grid.
- 30 12. The method of claim 9, wherein regulating the current flowing
through the energy storage device comprises regulating an amount and phase of the
current flowing through the energy storage device.

13. The method of claim 9, wherein calculating an instantaneous value of the reference current comprises generating a waveform of the reference current by a phase locked loop circuit based on a waveform of the grid voltage (V_{grid}).

5 14. The method of claim 9, wherein operating switches of a grid frequency rectifier comprises operating the switches of the grid frequency rectifier switches in synchronization with zero crossings of the grid voltage (V_{grid}).

15. A system for controlling reactive power, the system comprising:
10 a utility grid;
at least one reactive power compensator coupled to the utility grid, the reactive power compensator comprising:
a power stage circuit comprising,
a grid frequency rectifier configured to connect to the utility
15 grid,
a high frequency inverter connected to the grid frequency rectifier, and
an energy storage device connected to the high frequency inverter; and
20 a controller configured to operate the power stage circuit to provide VAR support to the utility grid, the controller being configured to,
switch switches in the grid frequency rectifier in
synchronization with zero crossings of a grid voltage of the utility
grid, and
25 operate the high frequency inverter in duty cycle modulation.

16. The system of claim 15, wherein switches in the high frequency inverter are switched on and off at a switching frequency equal to or more than ten times frequency of the grid voltage.

30 17. The system of claim 15, wherein the duty cycle of the high frequency inverter is calculated based on instantaneous measurement of utility grid current and an amount of reactive power required in the utility grid.

18. The system of claim 15, wherein the energy storage device is an inductor.
- 5 19. The system of claim 15, wherein the grid frequency rectifier and the high frequency inverter each comprises four switches.
20. The system of claim 15, wherein the switches in the grid frequency rectifier and the high frequency inverter are metal oxide semiconductor field effect
10 transistor (MOSFETs) or insulated gate bipolar transistor (IGBT).

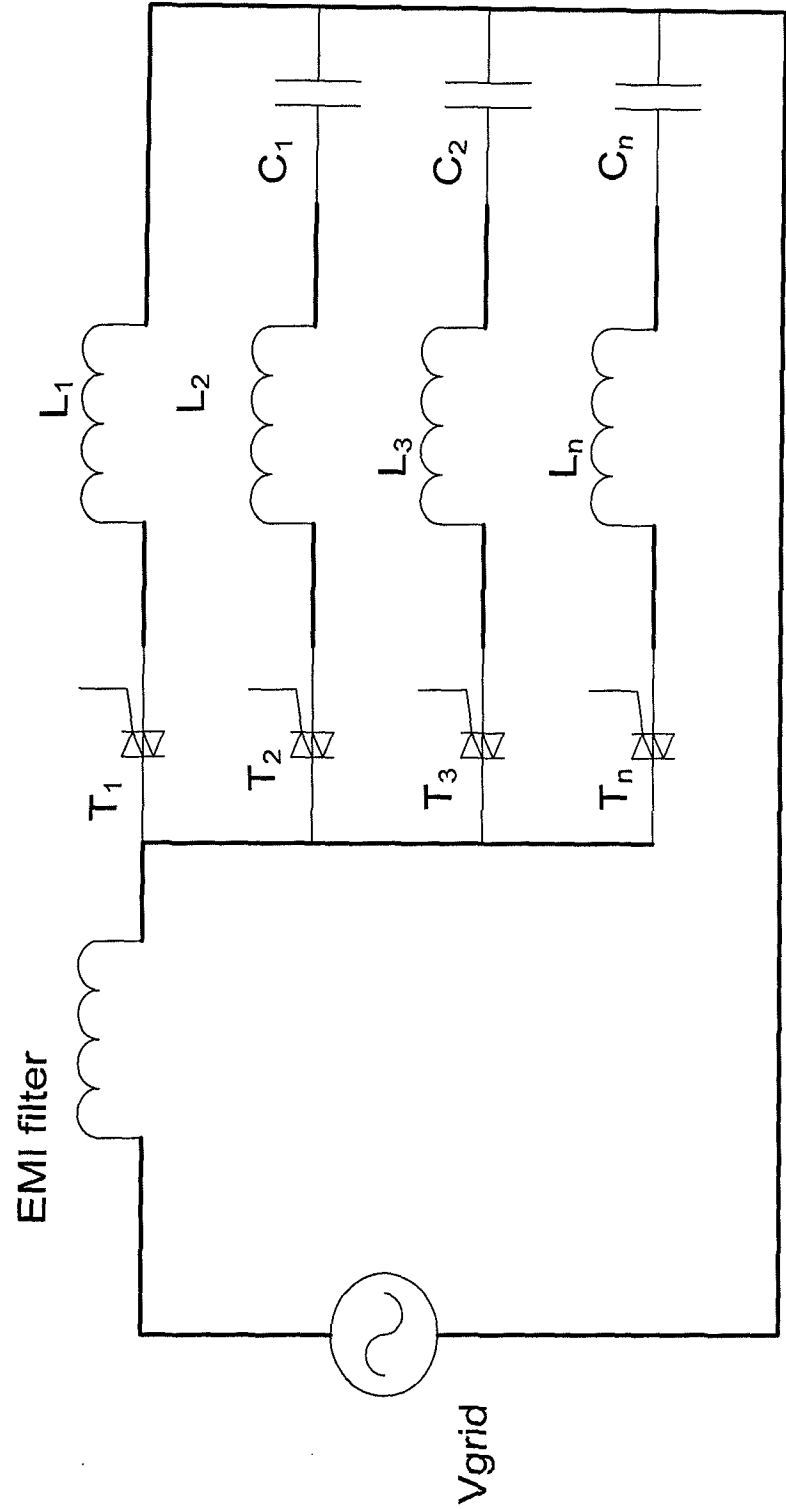
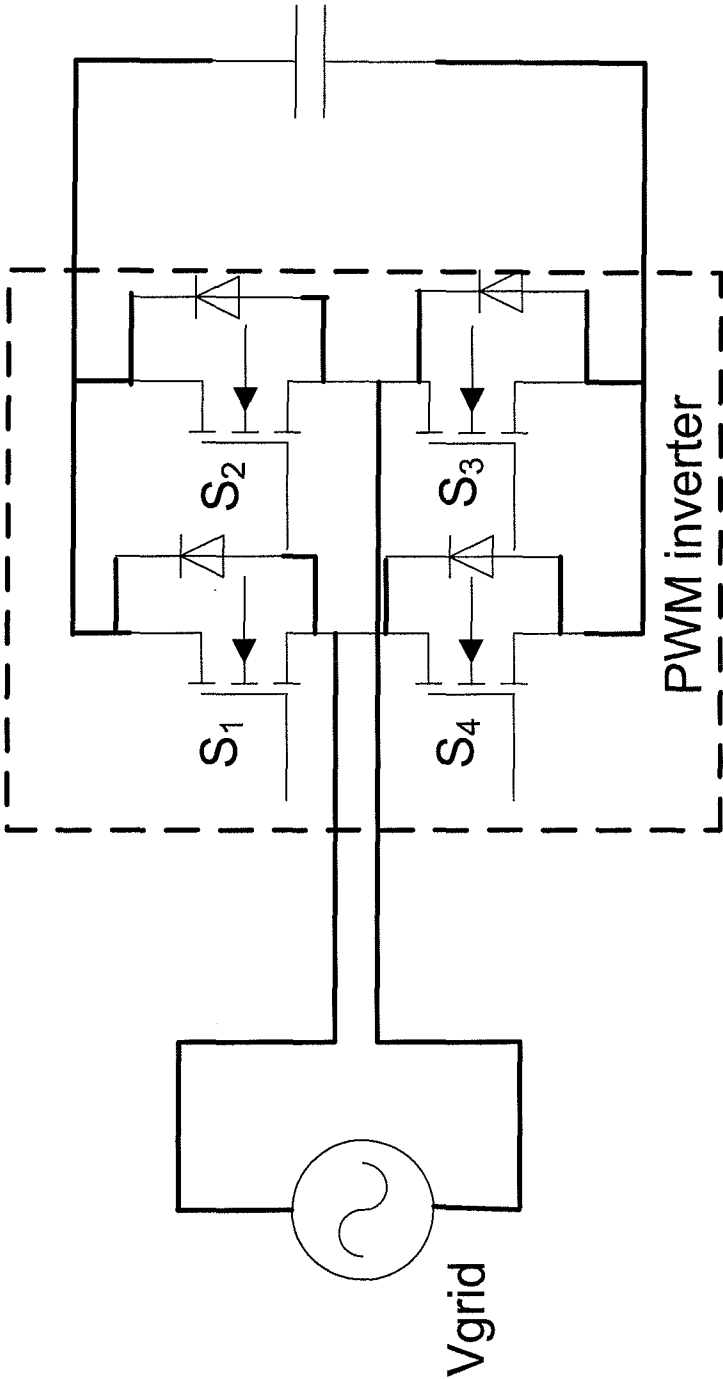


FIG. 1

PRIOR ART



PRIOR ART

FIG. 2

300

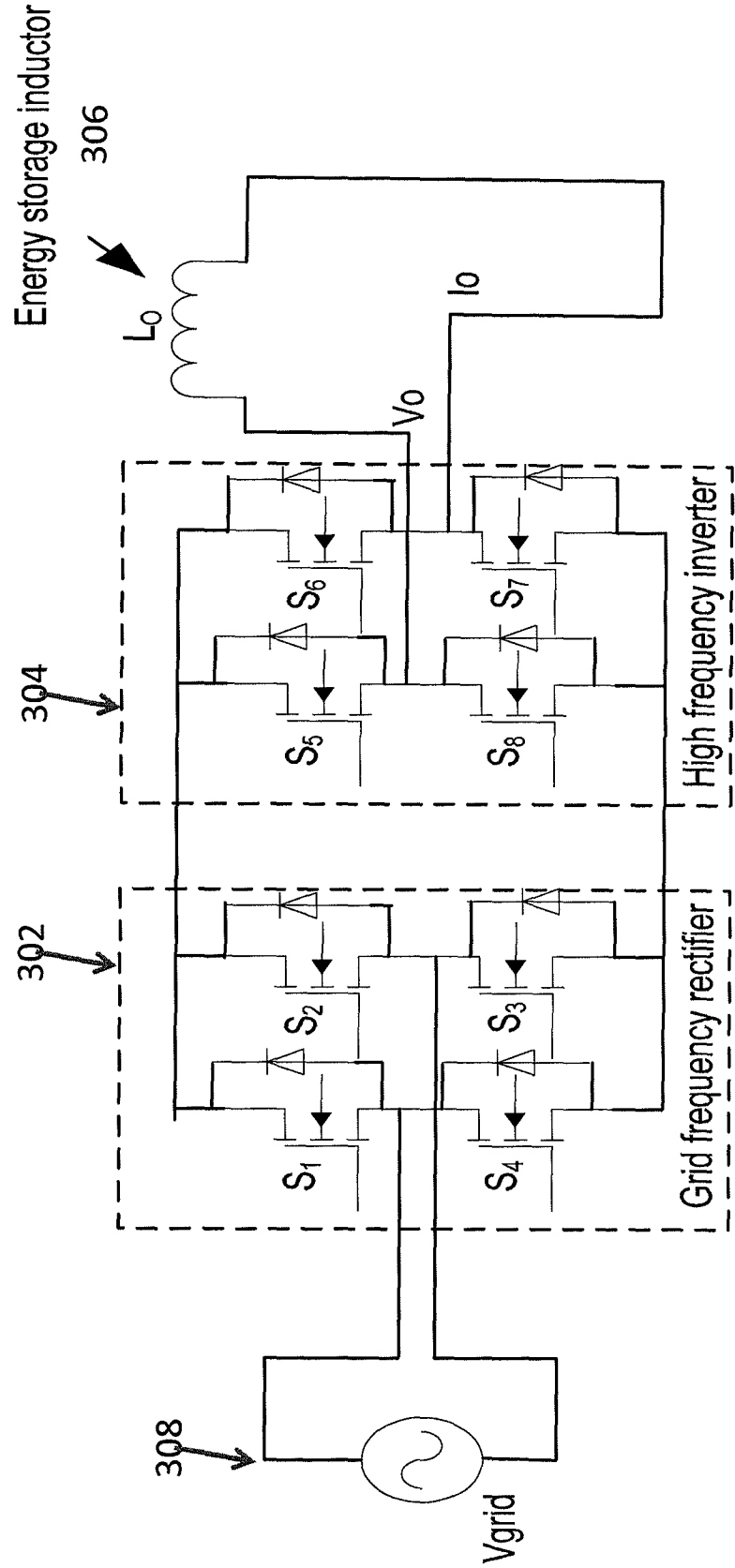


FIG. 3

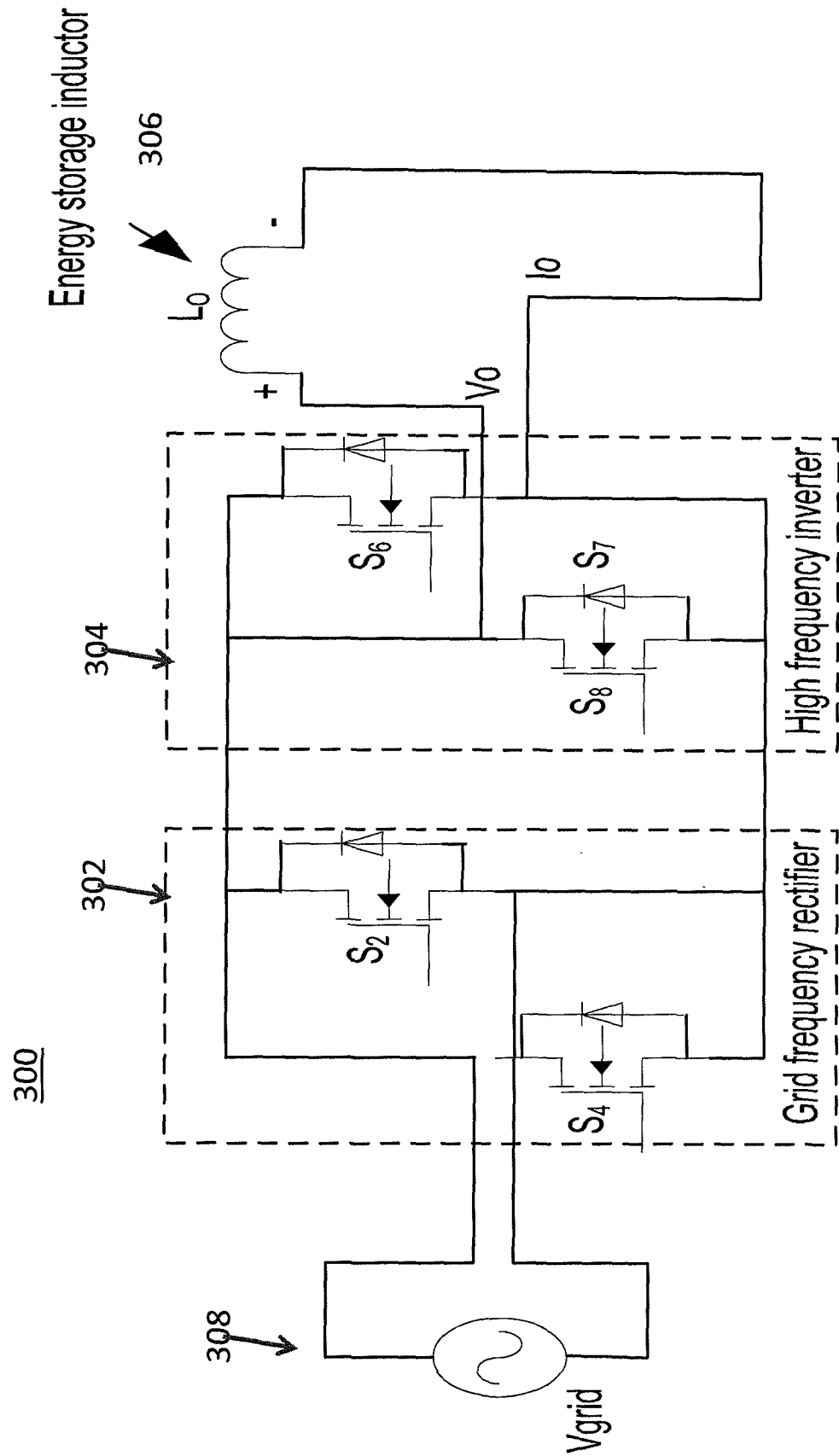


FIG. 4

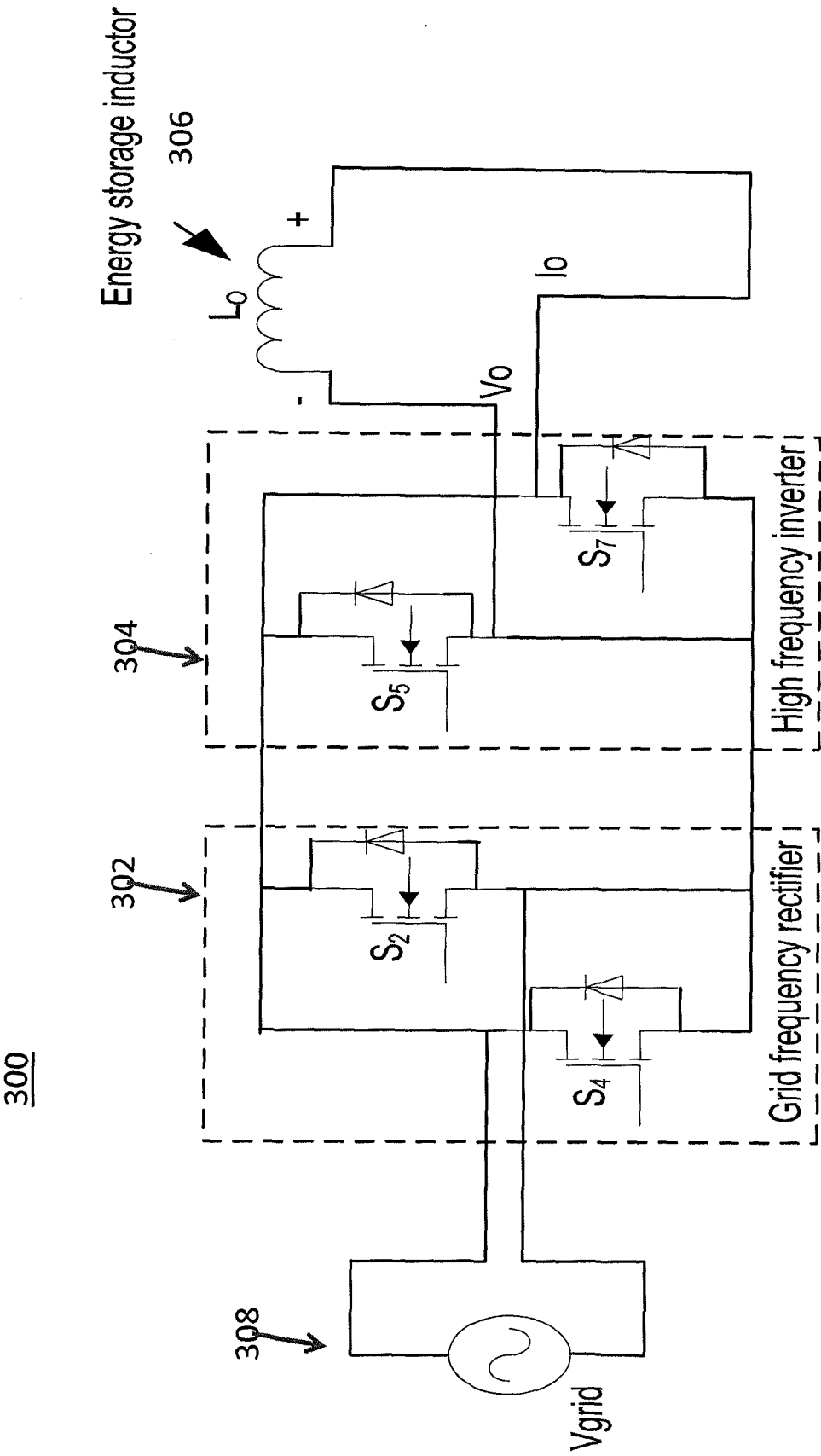


FIG. 5

300

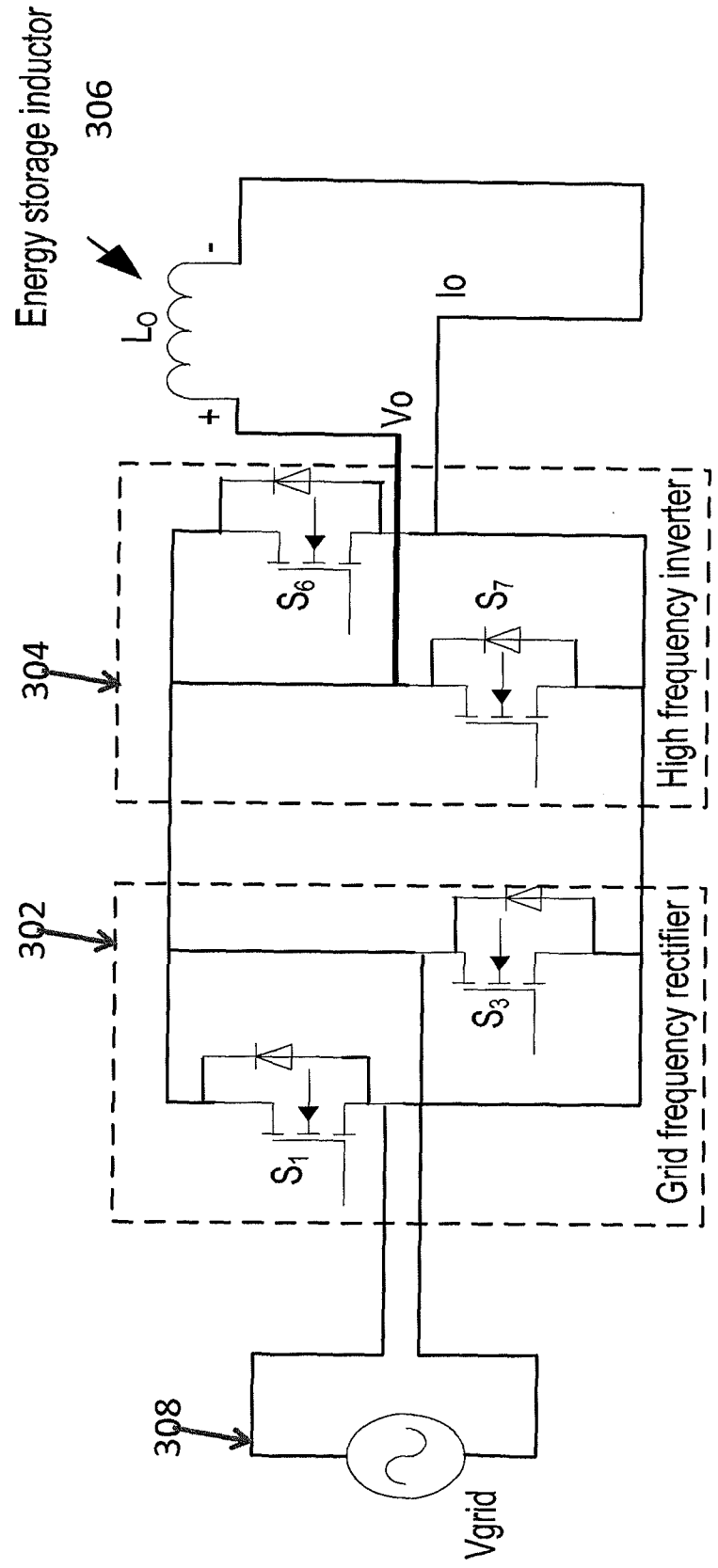


FIG. 6

300

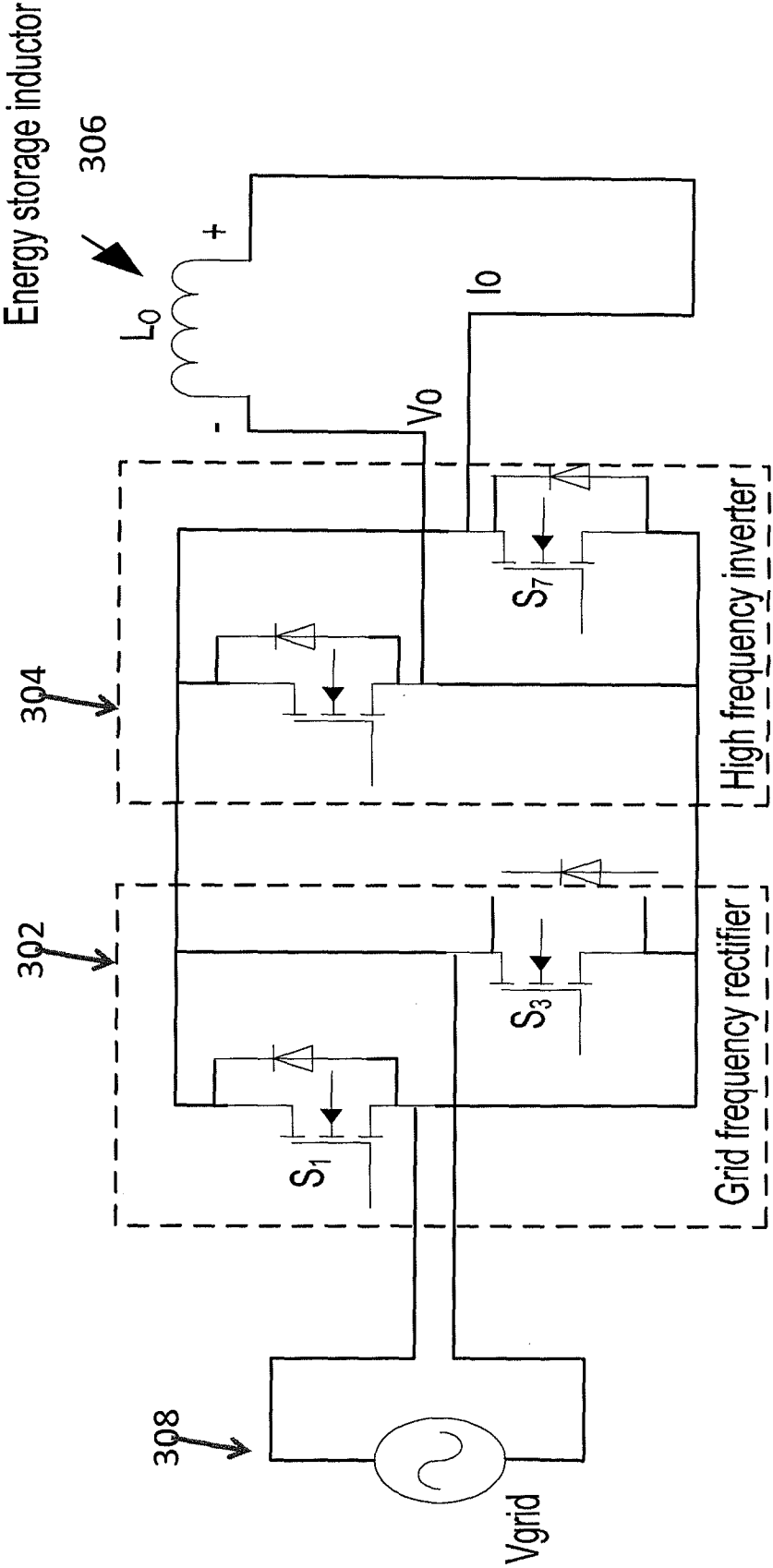


FIG. 7

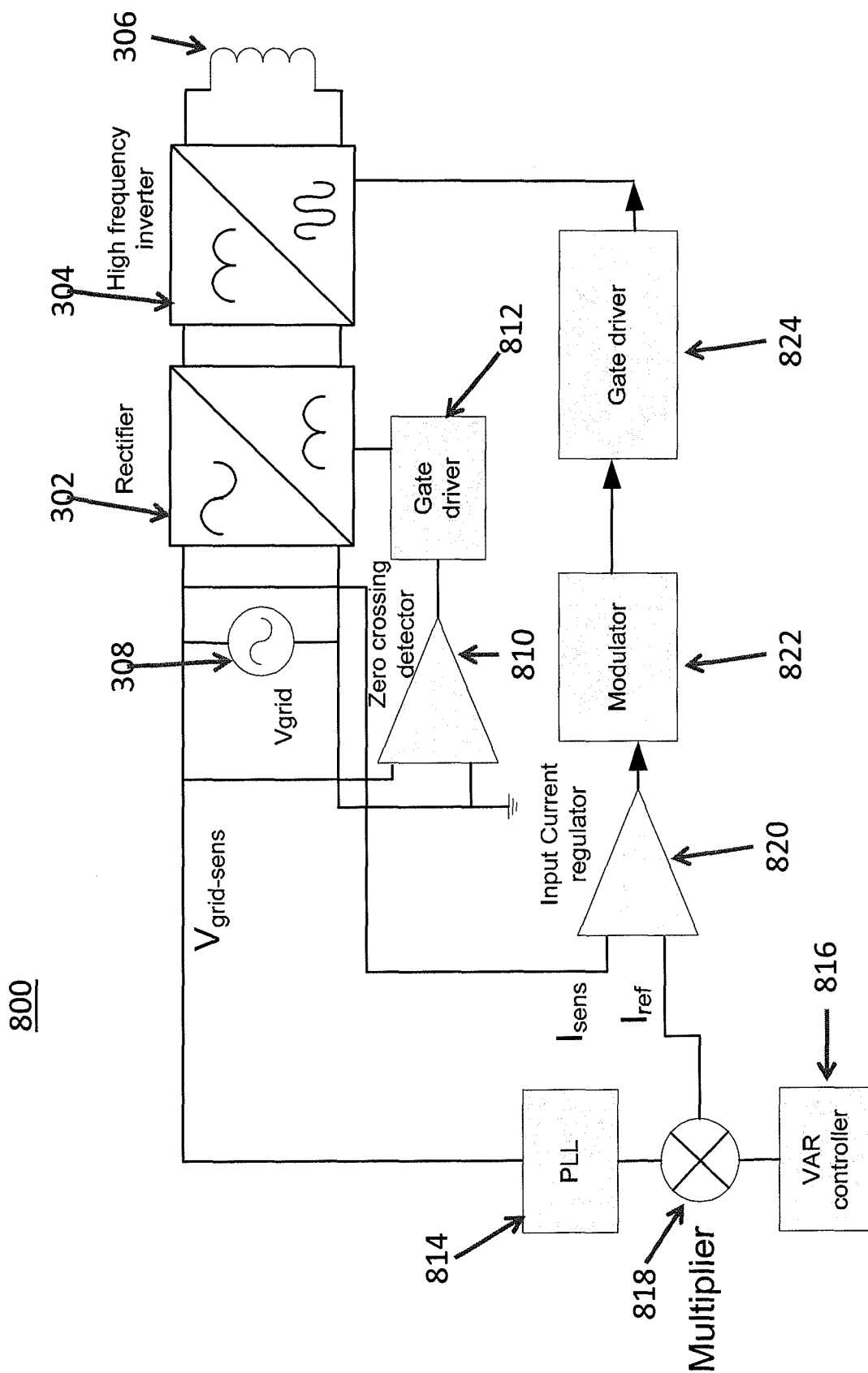


FIG. 8

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2012/033591

A. CLASSIFICATION OF SUBJECT MATTER IPC(8) - G05F 1/70 (2012.01) USPC - 323/207 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) IPC(8) - G05F 1/10, 12, 40, 54, 569, 66, 70, 5/00 (2012.01) USPC - 305/ 205, 206, 207, 210, 214, 219 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) Orbit, Google Patents, Pro Quest		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	ZHAO. Design and control of a cascaded H-bridge converter based solid state transformer (SST). ProQuest Dissertations and Theses. 2010. [13.07.2012] Retrieved from internet: < http://search.proquest.com/docview/853068143?accountid=142944> entire document	1-20
Y	US 6,700,804 B1 (REICHARD) 02 March 2004 (02.03.2004) entire document	1-20
Y	US 6,075,350 A (PENG) 13 June 2000 (13.06.2000) entire document	4, 9-14, 17
A	US 2008/0062724 A1 (FENG et al) 13 March 2008 (13.03.2008) entire document	1-20
☐ Further documents are listed in the continuation of Box C. ☐		
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Date of the actual completion of the international search 13 July 2012		Date of mailing of the international search report 08 AUG 2012
Name and mailing address of the ISA/US Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-3201		Authorized officer: Blaine R. Copenheaver PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774