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- (54) Title: METHOD AND SYSTEM FOR A LOW COST BI-DIRECTIONAL GRID TIED PHOTOVOLTAIC (PV) MICRO INVERTER

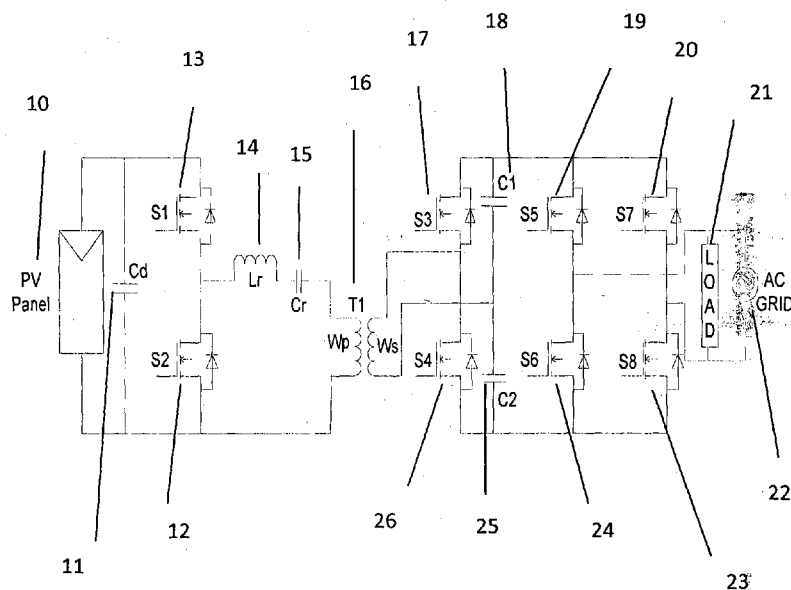


FIG.1

(57) Abstract: The proposed invention is a Low cost bi-directional Photovoltaic (PV) microinverter providing bi-directional power flow between a load and plurality of power sources and also between said plurality of power sources. It has a cascade connection of a decoupling capacitor, a switching stage having half bridge configuration, a resonant tank circuit (series connection of inductor and capacitor), a high frequency transformer, filter capacitors and a low frequency switching network consisting of semiconductor switches configured in full bridge arrangement.



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TITLE

Method and system for a Low cost bi-directional Photovoltaic(PV) microinverter

5 FIELD OF THE INVENTION

The present invention relates to solar inverters, micro inverters and AC modules and more particularly a (photovoltaic) PV inverter designed to work for the bi-directional power flow between the grid and PV source.

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BACKGROUND OF THE INVENTION

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Most of the present day PV inverters are based on the string inverter type of technology wherein many solar panels are connected in series. Although the cost of generation is lower in such installations, failure of one panel can take down the entire inverter.

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Another disadvantage of the string inverters is large area requirement for solar panels installation. In places where the land costs are high, this may not be a preferred choice. One more issue with the string inverters is the maximum power of the solar panel is tracked based on the entire string. So the effective yield of the system is lower in comparison with the systems which are not based on the string inverter technology. One of the technologies which offer a decentralised solution to all the above mentioned problems is the micro-inverter based technology. In this type, one inverter is connected to each solar panel. In a typical grid tied systems, this inverter converts the DC voltage from the solar panel in to an AC voltage and then transfers all the energy in to the electrical grid.

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The field of PV micro-inverters is relatively new. State of the art micro-inverters have in general two types of architectures, namely single stage or a two stage. In single stage architectures, there is only one switching stage for conversion from

- solar panel DC voltage in to AC voltage. In this type, first the low DC voltage from the solar panel is converted in to a pulsating DC voltage. This pulsating DC voltage has a pulse frequency of two times the desired AC voltage frequency. The shape of this DC voltage is similar to a modulus performed on a sine wave. This
- 5 pulsating DC voltage is converted in to AC voltage by a low frequency switching network. Typically this switching network switches at the frequency of desired AC voltage. International application No. PCT/US2011/034981, titled "*Method and System For Controlling Resonant Converters Used in Solar Inverter*," has discussed one such single stage topology using a resonant DC to DC converter.
- 10 The use of such converters increases the efficiency of the circuit. U.S. Patent No.7319313 titled "*Photovoltaic DC-to-AC power converter and control method*," has also presented one more single stage architecture using a combination of boost and buck converters.
- 15 In two stage architectures, there are two switching stages for DC to AC conversion. In this type of architecture, the low DC voltage from the solar panel is first amplified to a high DC voltage by a high frequency transformer and high frequency DC –DC converter switching circuit. This high DC voltage is later on converted to AC voltage by another high frequency DC to AC converter. U.S.
- 20 Patent No.7479774 titled "High performance solar photovoltaic (PV) energy conversion system," discusses one such topology.

Regardless of their type, all the PV inverters are faced with many challenges such as achieving high efficiency, low component cost and high reliability. As the

25 number of grid connected systems is growing, there is another challenge of supplying reactive power for dynamic grid stability at the point of connection for the grid tied inverter.

To achieve this, grid tied PV inverter needs to support power flow from the

30 inverter to the grid and vice versa. This is also known as bi-directional power flow for reactive power compensation. Two stage architectures support bi-directional

power flow since they have a dynamic storage device with an additional switching stage. But, they are significantly less efficient in comparison with single stage architectures. Additional switching stage makes the overall power conversion process less efficient. Most of the single stage architectures are very efficient since they have only one switching stage. However, they are designed in such a way that bi-directional power flow is not possible with them. Achieving high efficiency and bi-directional power flow is a difficult task. There have been recent efforts to address this issue. US patent application No 2012/0290145 titled "*Single Stage Grid-Connected Solar Inverter for Distributed Reactive Power Generation*," and USPTO Application number PCT/US11/34981 titled, "*Topology and Control for Distributed VAR Generating Solar Inverters*," have presented two single stage topologies which can work in bi-directional mode. Although both the topologies are designed for achieving high efficiency, the design of driver circuits for both the topologies is more difficult. This increases the overall cost of the system.

Pursuant to analysing the prior art and comparing a single stage topology with a double stage topology it is clear that the main advantage of the single stage micro-inverter topology over the double stage topology is that of higher efficiency due to lesser number of switching stages. However most of the single stage topologies do not support bi-directional power flow between the converter and electric grid. This is necessary for providing reactive power for grid stability.

OBJECTIVE OF THE INVENTION:

1. It is primary objective of present invention to provide grid tied PV micro-inverter supporting bi-directional power flow between PV and grid.
2. It is another objective of present invention is to provide bi-directional power using a single switching stage.

3. It is another objective of present invention is to provide grid tied PV micro-inverter with minimum number of components.

4. It is another objective of present invention is to provide grid tied PV micro-inverter with high efficiency.

5. It is another objective of present invention is to provide grid tied PV micro-inverter with low cost.

6. It is another objective of present invention is to provide grid tied PV micro-inverter which has high reliability.

7. It is another objective of the present invention is to used as one of islanded mode and no grid connection.

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SUMMARY OF THE INVENTION:

The proposed invention here presents a micro-inverter topology which converts the DC voltage output from the solar panel in an AC voltage. This topology has a cascade connection of a decoupling capacitor, a switching stage having half bridge configuration, a resonant tank circuit (series connection of inductor and capacitor), a high frequency transformer, filter capacitors and a low frequency switching network consisting of semiconductor switches configured in full bridge arrangement. The way topology has been designed, it has several advantages. First of all, there is only one decoupling capacitor unlike other half bridge arrangement where one needs to be careful about balancing equal voltages across the two input capacitors. The second advantage is use of series LC resonant circuit. This allows the use of higher switching frequencies with reduced switching losses. Third advantage is the efficient transformer design. The number of turns in a transformer is directly proportional to the applied voltage. The use of half bridge reduces the applied voltage on the transformer primary by half. In addition to this,

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the voltage doubler reduces the turns ratio and hence the required number of secondary turns. The fourth advantage is use of MOSFETs for synchronous rectification. This allows the bi-directional power flow from PV to the grid and vice versa. At last the DC to AC conversion is done by a low frequency switching
5 circuit. This makes the overall circuit efficiency very high.

BRIEF DESCRIPTION OF DRAWING:

Figure 1 shows a schematic diagram of PV micro-inverter in accordance with an
10 aspect of the present invention.

Figure 2 shows first switching states of inverter mode in accordance with an aspect of the present invention.

Figure 3 shows second switching states of inverter mode in accordance with an aspect of the present invention.

15 Figure 4 shows third switching states of inverter mode in accordance with an aspect of the present invention.

Figure 5 shows fourth switching states of inverter mode in accordance with an aspect of the present invention.

20 Figure 6 shows gate drive signals for the switches S5, S6, S7 and S8 in accordance with an aspect of the present invention.

Figure 7 shows a block diagram of control scheme for PV micro-inverter in the grid tied mode in accordance with an aspect of the present invention.

Figure 8 shows a block diagram of control scheme for PV micro-inverter in off the grid mode in accordance with an aspect of the present invention.

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DETAILED DESCRIPTION OF INVENTION:

The present invention proposes a bi-directional PV micro inverter and the same is explained below with reference to the accompanying drawings in accordance with
5 an embodiment of the present invention.

Figure 1 illustrates the proposed power circuit diagram of the invention. It consists of a cascade connection of a half bridge converter formed by first switches S1(13) and second switch S2 (12), a series LC resonant circuit formed by
10 inductor Lr(14) and Cr(15), a high frequency transformer denoted by transformer T1(16), synchronous rectifier formed by third and fourth switches S3(17) and S4(26), first and second filter capacitors C1(18) and C2 (25) and a line frequency switching network formed by fifth switch S5(19), sixth switch S6(24), seventh switch S7(20) and eighth switch S8(23). The power circuit has a single PV
15 panel(10) at its input. All the switches in the power circuit are controllable, that is MOSFETs.

The power circuit is designed to operate essentially in two modes based on the way energy is transferred.

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1. Inverter mode
2. Grid energy storage mode

The power circuit operates in the inverter mode if the power is transferred from the PV side to the load. The circuit operates in the energy storage mode when the
25 power is transferred from the grid to the energy storage device connected on the PV side.

In inverter mode, the switches S1 (13) and S2(12) are operated in complementary manner and are either frequency or duty cycle modulated. They along with the
30 resonant tank components Lr (14) and Cr (15) vary the voltage across the winding Wp of the high frequency transformer T1 (16). The transformer amplifies this

voltage. The switches S3 (17) and S4 (26) together act as synchronous rectifier and convert it in to a pulsating DC voltage along with the first and second capacitors C1 (18) and C2 (25). Together they form a voltage doubler circuit. The switches S5(19), S6(24), S7(20) and S8(23) are always synchronised with the grid voltage. Grid voltage itself may be generated by standard electricity grid network or it may also be generated by another inverter or a microinverter or any other electricity generator. If the converter is operated in voltage control mode then the switches S5 (19), S6(24), S7(20) and S8(23) are synchronised with the sine reference generator(22). Due to this synchronised operation with the grid or sine reference generator (22), they convert the pulsating voltage across C1(18) and C2(25) in to grid compatible AC voltage. The current flow can be bi-directional since all the switches used here are MOSFETs. The circuit goes through four distinct switching states of operation. .

Figure 2 illustrates the first switching state where the S1(13) is turned on and the voltage across Wp of T1(16) is positive. The switch S3(17) is also on. C1 (18) gets charged to half of the pulsating DC voltage. Switches S5(19) and S8(23) are on to synchronise with positive grid voltage cycle.

Figure 3 illustrates the second switching state where switch S2(12) and S4(26) are on and charge the capacitor C2(25) to another half of the pulsating DC voltage. The total voltage across C1 (18) and C2 (25) is equivalent to the rectified line voltage. The switches S5 (19) and S8 (23) are kept on to keep the same positive grid voltage cycle.

Figure 4 illustrates the third switching state where the S1(13) is turned on and the voltage across Wp of T1(16) is positive. The switch S3(17) is also on. C1(18) gets charged to half of the pulsating DC voltage. Switches S6(24) and S7(20) are on to synchronise with negative grid voltage cycle.

Figure 5 illustrates the fourth switching state where switch S2(12) and S4(26) are on and charge the capacitor C2(25) to another half of the pulsating DC voltage.

The total voltage across C1 (18) and C2 (25) is equivalent to the rectified line voltage. The switches S6 (24) and S7 (20) are kept on to keep the same negative grid voltage cycle.

- 5 The current flow in all the switching states can be bi-directional.

Figure 6 illustrates synchronised gate signals for the switches S5(19), S6(24), S7(20) and S8(23) with the grid voltage.

- 10 Grid energy storage mode is used while connecting an energy storage element. The energy storage element is represented by the capacitor Cd (11) in the circuit. The storage element itself can be a super or ultra capacitor with very high capacitance value or a battery. In this mode the switches S5(19), S6(24), S7(20) and S8(23) act as synchronous grid frequency rectifier. Switches S1(13) and S2
15 (12) control the current in the converter. In this mode the instant to instant circuit states are similar to the ones shown in Figure 2 to 5.

Overall control scheme in the inverter mode:

- 20 Figure 7 illustrates the overall control scheme for this topology in the grid tied mode. The inverter is capable of operating in the grid tied and off the grid mode. In the grid tied mode, the circuit works in the current control mode. In this mode the control variable is output current. It is sensed using a current sensor and is processed using a signal conditioning circuit for it to be used by the controller
25 (42). The signal conditioning circuit can be an amplifier in the simplest case. The controller (42) can be anything like a microprocessor or a microcontroller or a set of logic gates or in the most simple case, an analog circuit. If the controller is a microprocessor or a microcontroller then the output of the signal conditioning circuit is given to an analog to digital converter. The grid voltage is sensed by the
30 voltage sensor and it is further processed by a signal conditioning circuit and an

analog to digital converter whose output is given to the controller (42). Controller (42) uses it to generate the waveshape of the reference current and also to determine the phase of the reference current. The PV voltage and PV current are sensed by controller using a set of sensors, signal conditioning circuit and an analog to digital converter. Controller runs the Maximum Power Point Tracking (MPPT)(40) algorithm using this information and derives the magnitude of the reference current. In addition to generating active power, the inverter also generates VARs or the reactive power. A VAR controlling unit in the controller takes the input from the user to generate the phase angle of the reference current.

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Once the magnitude, waveshape and the phase angle of the reference current are known, the compensator block of the controller calculates the difference between the actual current and the reference current. The controller applies either proportional or proportional integral (PI) or proportional integral and derivative (PID) control to the error amplifier output and calculates the required duty cycle (D)(43) and frequency (F) (44) for the inverter switches S1(13) and S2 (12). Sometimes, controller (42) also applies a feed-forward control to the error signal. After the control action, the controller outputs a logic level pulse width modulated and frequency modulated signal with desired frequency and duty cycle. This signal is applied to a gate driver circuit. Output of the gate driver circuit is given to the control input of the controllable switches S1(13) and S2 (12).

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Figure 8 illustrate the overall control scheme for the inverter in the off the grid mode. In the off the grid mode, the inverter control variable is output voltage. The output voltage reference is generated by either a sine function look up table or by any sine wave generator (34). The inverter output voltage is sensed and compared with the reference voltage and PWM signals with desired duty cycle and frequency are generated by using any of the closed loop control algorithms. The actual control mechanism is similar to the output current control described IN figure 7.

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A separate DC to DC converter (44) along with the battery (45) may be connected in parallel with PV(30) for this mode.

5 Energy storage mode is used when the inverter is used to store the energy in the AC grid (34). The inverter acts as AC to DC converter. First the unfolder switches S5(19), S6(24), S7(20) and S8(23) rectify the AC voltage in to a pulsating DC voltage. The switches S_1 and S_2 are frequency and duty cycle modulated to control the current in an energy storage device like battery in the absence of PV power. A separate DC to DC converter along with the battery is
10 connected in parallel with PV for this mode.

The above description along with the accompanying drawings is intended to be illustrative and should not be interpreted as limiting the scope of the invention. Those skilled in the art to which the invention relates will appreciate that many
15 variations of the described example implementations and other implementations exist within the scope of the claimed invention.

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What is claimed is:

1. A system for bidirectional PV (Photovoltaic) microinverter comprising of:
 - a PV panel to generate DC voltage;
 - a decoupling capacitor coupled with the PV panel;
 - 5 a half bridge converter is coupled with the decoupling capacitor;
 - a LC resonant circuit is coupled with the half bridge converter;
 - a high frequency transformer T1 is coupled with the LC resonant circuit;
 - a synchronous rectifier is coupled with the high frequency transformer T1;
 - 10 a plurality of filter capacitors are coupled with the synchronous rectifier; and
 - a line frequency switching network coupled with the plurality of filter capacitors;
- 15 2. The system for bidirectional PV (Photovoltaic) microinverter as claimed in claim 1, wherein each component further comprising of at least an input and an output terminal;
3. The system for bidirectional PV (Photovoltaic) microinverter as claimed in claim 1, wherein the output of said PV panel is fed to the input of said decoupling capacitor.
- 20 4. The system for bidirectional PV (Photovoltaic) microinverter as claimed in claim 1, wherein the output of said decoupling capacitor is fed to the input of said half bridge converter.
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5. The system for bidirectional PV (Photovoltaic) microinverter as claimed in claim 1, wherein the output of said half bridge converter is fed to the input of said LC resonant circuit.
- 5 6. The system for bidirectional PV (Photovoltaic) microinverter as claimed in claim 1, wherein the output of said LC resonant circuit is fed to the input of said high frequency transformer.
7. The system for bidirectional PV (Photovoltaic) microinverter as claimed in claim 1, wherein the output of said high frequency transformer is fed to the input of said plurality of filter capacitors.
- 10 8. The system for bidirectional PV (Photovoltaic) microinverter as claimed in claim 1, wherein the output of said plurality of filter capacitors is fed to the input of said line frequency switching network.
- 15 9. The system for bidirectional PV (Photovoltaic) microinverter as claimed in claim 1, wherein said half bridge converter further comprises of switch S1 and switch S2.
- 20 10. The system for bidirectional PV (Photovoltaic) microinverter as claimed in claim 1, wherein said LC resonant circuit further comprises of inductor Lr and capacitor Cr.
- 25 11. The system for bidirectional PV (Photovoltaic) microinverter as claimed in claim 1, wherein said synchronous rectifier further comprises of switch S3 and switch S4.
- 30 12. The system for bidirectional PV (Photovoltaic) microinverter as claimed in claim 1, wherein said filter capacitors are C1 and C2.

13. The system for bidirectional PV (Photovoltaic) microinverter as claimed in claim 1, wherein said line frequency switching network further comprises of switch S5, switch S6, switch S7 and switch S8.

5 14. The system for bidirectional PV (Photovoltaic) microinverter as claimed in claim 1, wherein said switches S1, S2, S3, S4, S5, S6, S7 and S8 of claims 9, 11 and 13 can be formed using one or multiples of series and/or parallel connection of MOSFETs and/or diodes.

10 15. A method of facilitating bi-directional power flow between a load and plurality of power sources and also between said plurality of power sources comprising the steps of:

15 operating an inverter mode comprising of a first switch S1 and a second switch S2 in complementary manner and the first switch S1 and the second switch S2 are one of frequency and duty cycle modulated, a third switch S3 and a fourth switch S4 together act as synchronous rectifier and convert voltage generated by a transformer T1 into a pulsating DC voltage along with a first capacitor C1 and a second capacitor C2, a fifth switch S5, a sixth switch S6, a seventh switch S7 and an eighth switch S8 are always synchronized with a grid voltage; and

20 operative a grid energy storage mode comprising the fifth switch S5, the sixth switch S6, the seventh switch S7 and the eighth switch S8 act as synchronous grid frequency rectifier;

25 16. The method of facilitating bi-directional power flow between a load and plurality of power sources and also between said plurality of power sources as claimed in claim 15, which further comprising the steps of:

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a first switching state comprising said first switch S1 is turned on and voltage across a Wp of a transformer is positive wherein said third switch S3 is also on and said first capacitor C1 gets charged to half of the pulsating DC voltage further said fifth switch S5 and eighth switch are on to synchronize with positive grid voltage cycle;

a second switching state comprising the second switch S2 and the forth switch S4 are on and charge the second capacitor C2 to another half of the pulsating DC voltage wherein the fifth switch S5 and eighth switch S8 are kept on to keep positive grid voltage cycle;

a third switching state comprising the first switch S1 is turned on and the voltage across the Wp of the T1 is positive wherein the third switch S3 is turned on and first capacitor C1 gets charged to half of the pulsating voltage and further the sixth switch S6 and the seventh switch S7 are on to synchronized with negative voltage cycle; and

a forth switching state comprising the second switch S2 and forth switch S4 are on and charge the second capacitor C2 to another half of the pulsating DC voltage wherein a total voltage across first capacitor C1 and second capacitor C2 is equivalent to the rectified line voltage and further the sixth switch S6 and seventh switch S7 are kept on to keep the same negative voltage cycle;

17. The method of facilitating bi-directional power flow between a load and plurality of power sources and also between said plurality of power sources as claimed in claim 15, wherein the grid voltage itself maybe generated by one of a standard electricity grid network, an inverter, a micro-inverter and any other electricity generator.

18. The method of facilitating bi-directional power flow between a load and plurality of power sources and also between said plurality of power sources as claimed in claim 15, wherein said fifth switch S5, said sixth switch S6, said seventh switch S7 and said eighth switch S8 are
5 synchronized with a sine reference generator when the converter is operated in voltage control mode.

19. The method of facilitating bi-directional power flow between a load and plurality of power sources and also between said plurality of power sources as claimed in claim 15, wherein the current flow in all said
10 switching state is bi-directional.

20. The method of facilitating bi-directional power flow between a load and plurality of power sources and also between said plurality of power sources as claimed in claim 15, wherein said grid energy storage mode is
15 used while connecting an energy storage element.

21. The method of facilitating bi-directional power flow between a load and plurality of power sources and also between said plurality of power sources as claimed in claim 20, wherein said energy storage element is
20 represented by the capacitor C_d in the circuit.

22. The method of facilitating bi-directional power flow between a load and plurality of power sources and also between said plurality of power sources as claimed in claim 21, wherein said storage element itself is one
25 of a super, an ultra-capacitor with very high capacitance value and a battery.

Dated 02nd of May 2014

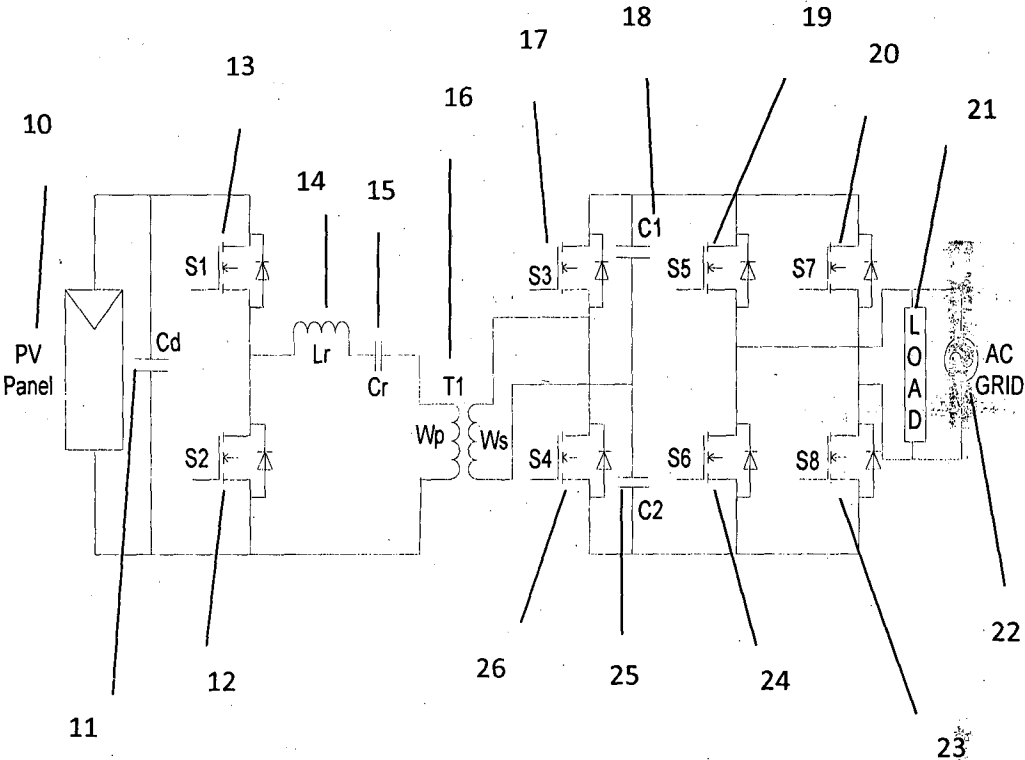
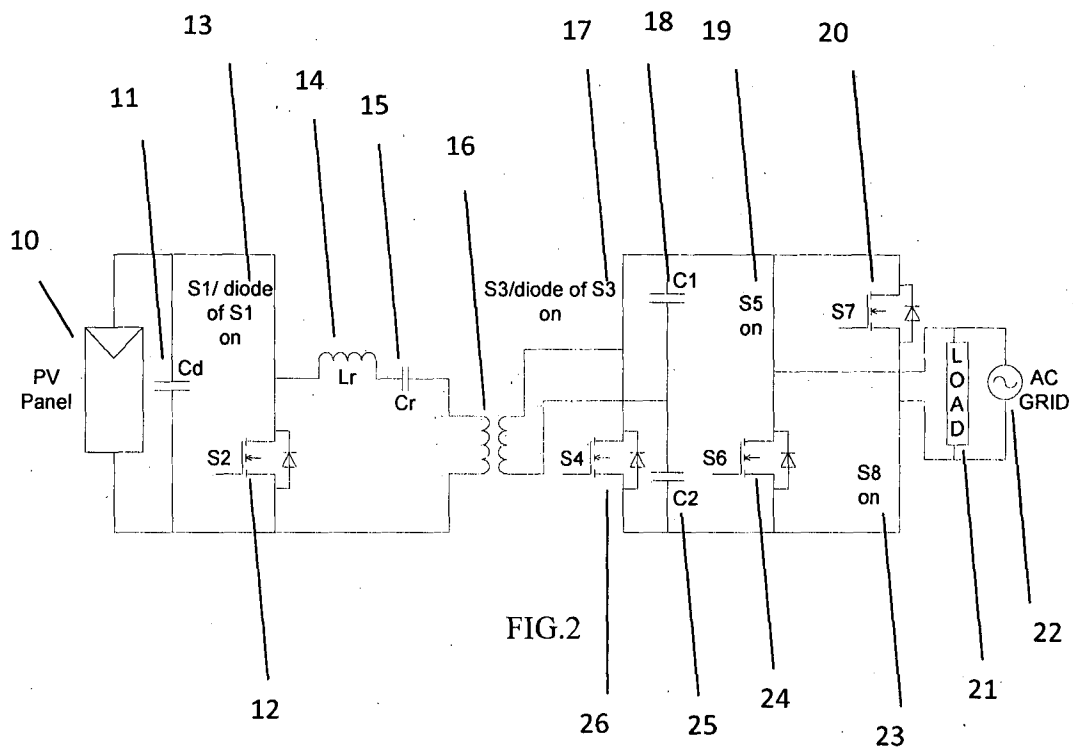


FIG.1



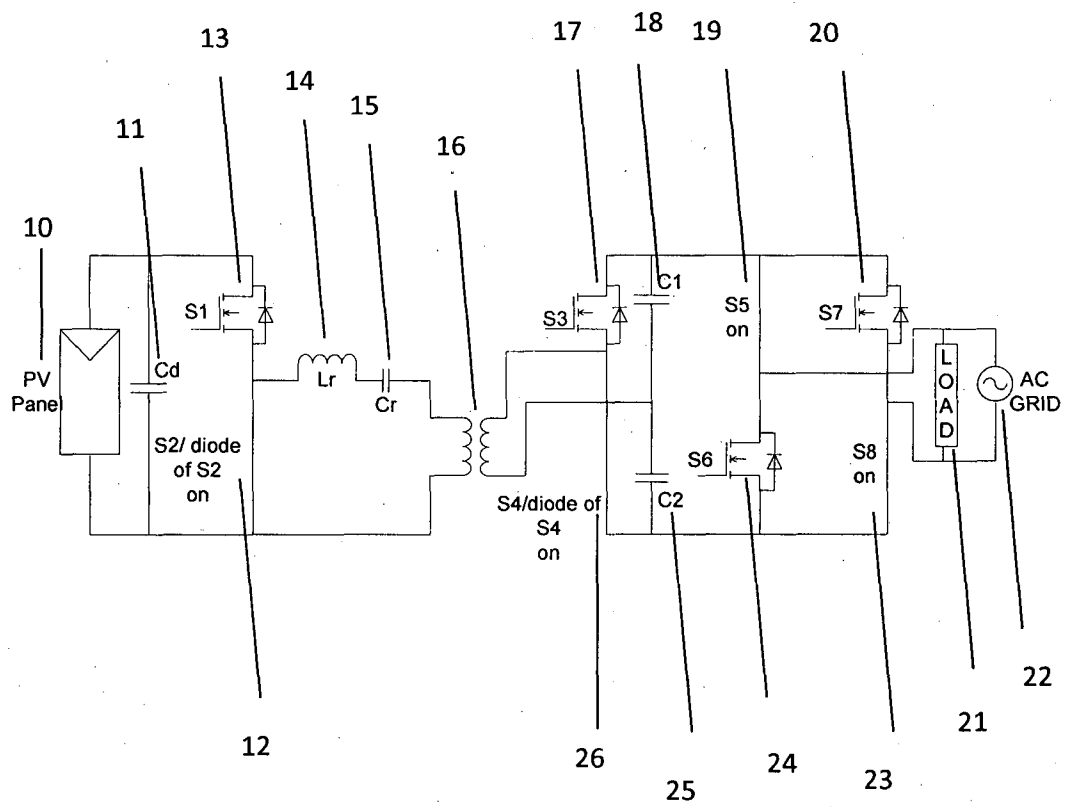


FIG.3

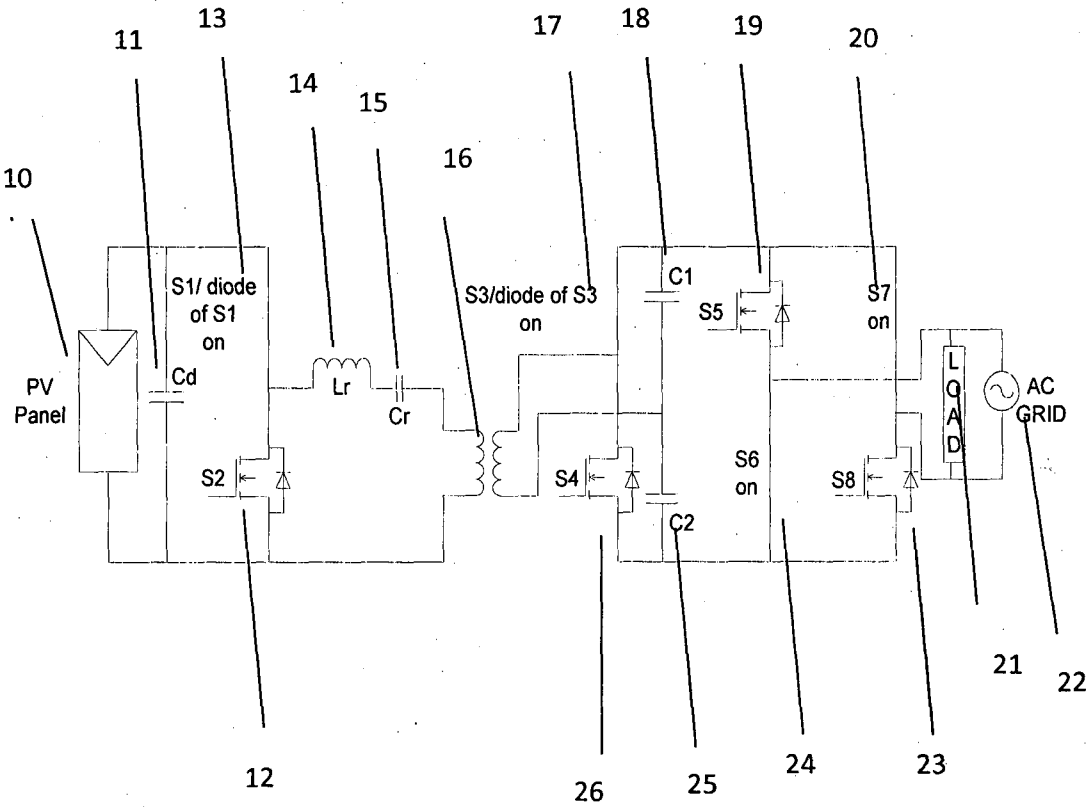


FIG.4

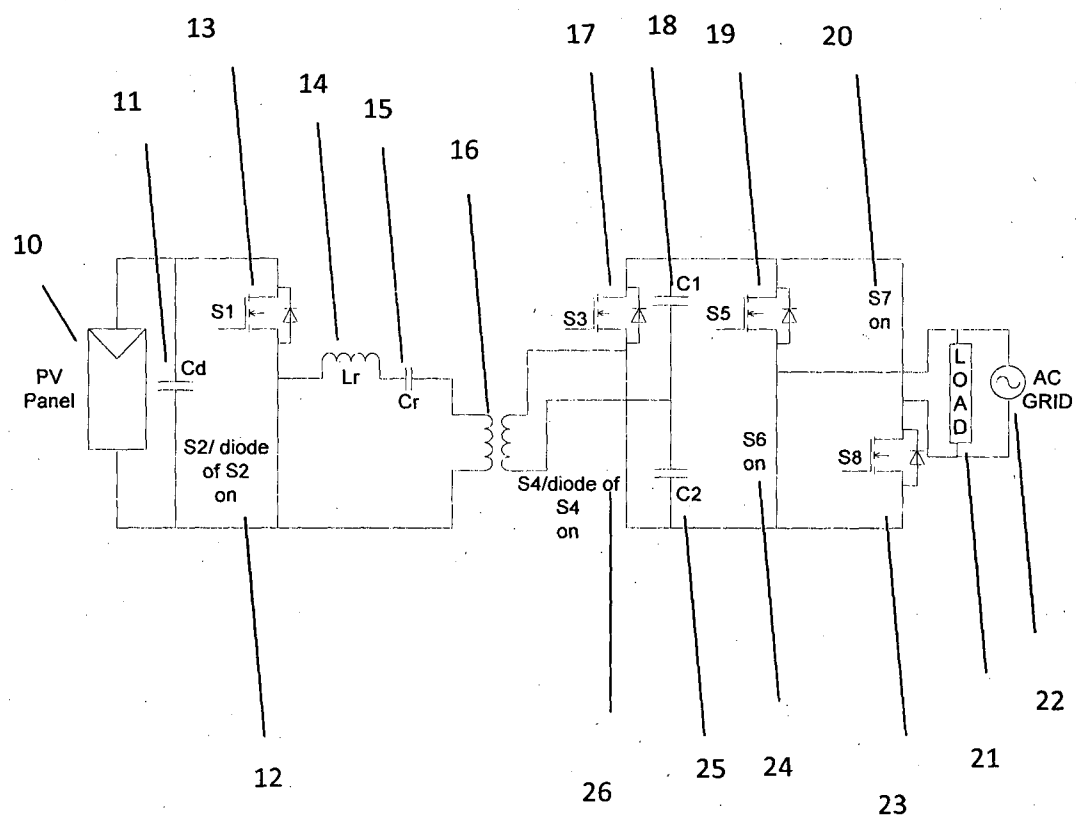


FIG.5

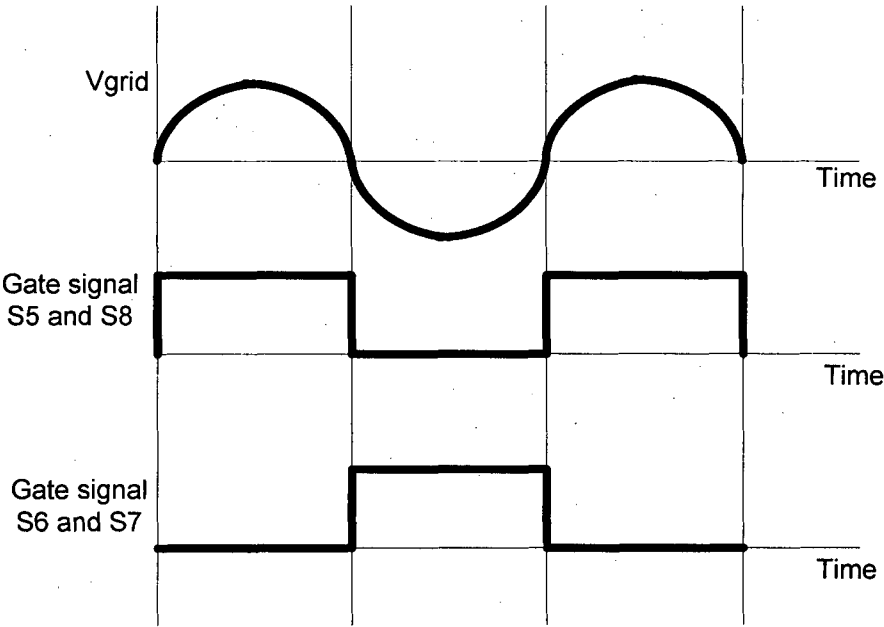


FIG.6

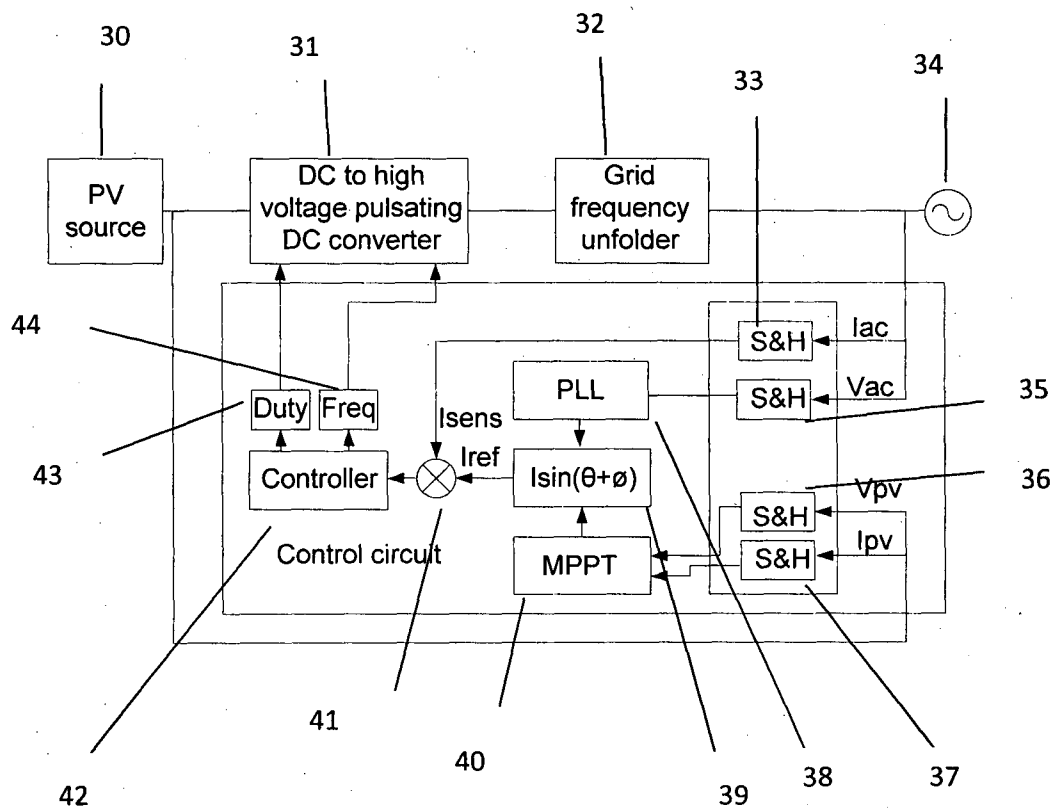


FIG.7

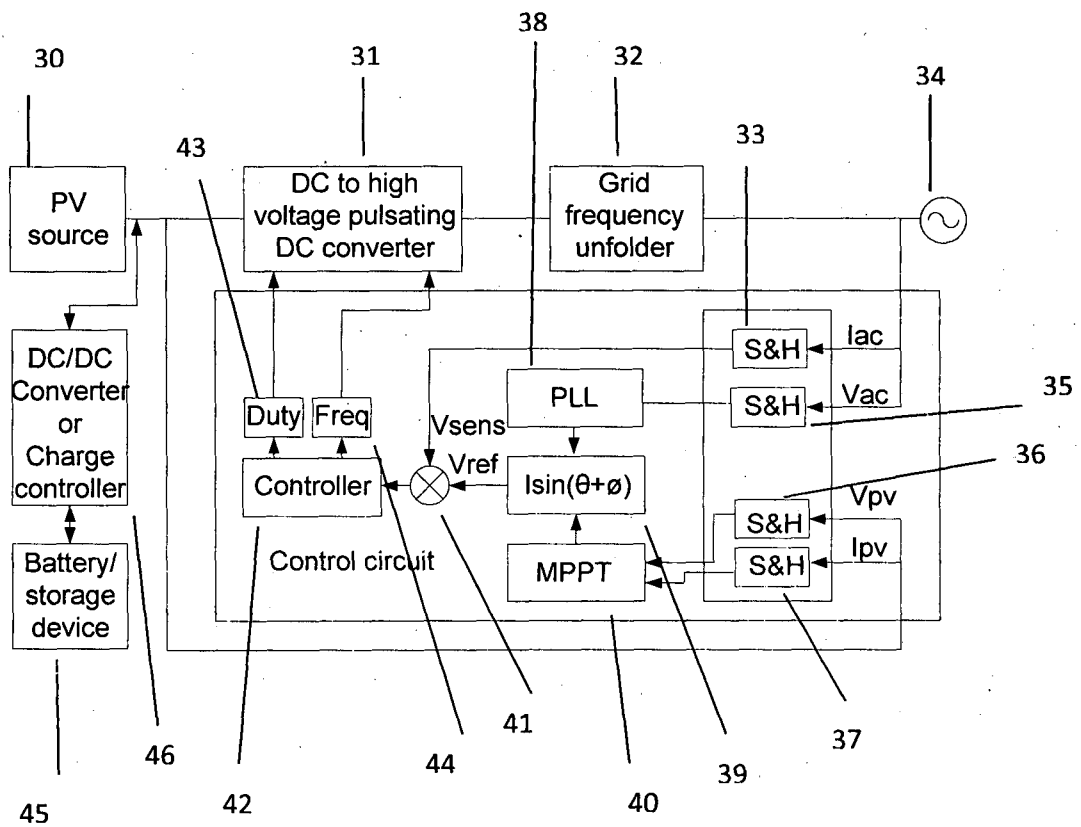


FIG.8