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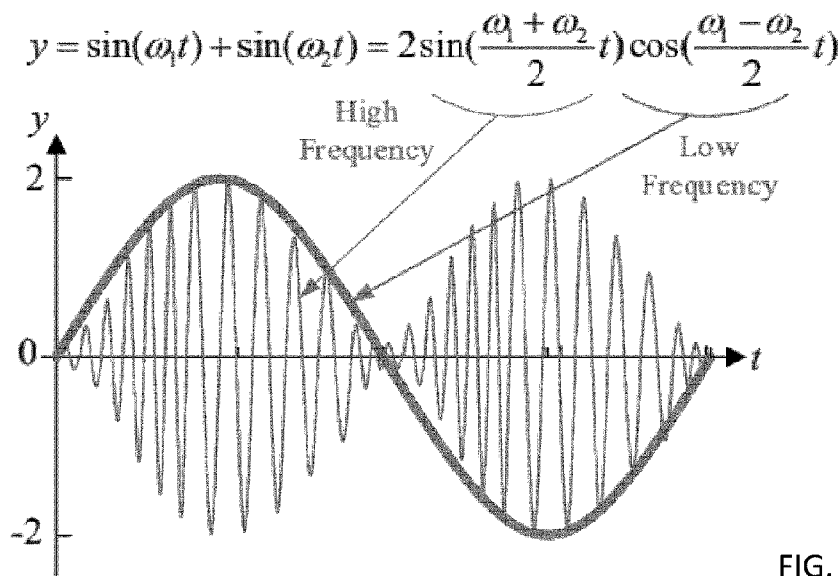


FIG. 1

(57) Abstract: A Beat Frequency Modulation (BFM) system for generating a low frequency reference waveform including two or more converters, a frequency control module, and a rectifier. The converters are connected in series, parallel, or cascaded. Each converter includes a power switch configured to generate a high frequency power signal controlled by BFM modules at their respective outputs. The frequency control module is configured to operate a BFM carrier signal of each of the converters at different frequencies, thereby creating an envelope of a resulting signal containing a desired low frequency reference signal. The rectifier is connected to outputs of the converters and configured to rectify the high frequency signal with the low frequency envelope shape, thereby generating a low frequency sinusoidal waveform.

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BEAT FREQUENCY MODULATED SINGLE-STAGE SOFT-SWITCHED MICROINVERTER

RELATED APPLICATIONS

[0001] This application claims priority benefit of U.S. Provisional Application Serial Number 63/452,725 filed 17 March 2023; the contents of which are hereby incorporated by reference.

FIELD OF THE INVENTION

[0002] The present invention generally relates to microinverters for photovoltaic (PV) systems, and more specifically to single-stage single-phase microinverters with soft-switching with fully soft-switching operation for a wide range of input voltage and output load based on beat frequency modulation (BFM).

BACKGROUND

[0003] Nowadays, photovoltaic (PV) systems are widely utilized in renewable energy systems due to their low costs and large power generation capacity [1]. To convert the low-level DC voltage of the PV panel (20~40V) to the desired AC voltage of the grid, a switching DC-AC power converter is required which is called the microinverter. In general, microinverters can be categorized into four groups according to the galvanic isolation (isolated and non-isolated structures), and the number of stages (single-stage and two-stage structures) [2].

[0004] To improve the power density of the power converter and decrease the cost and volume, the switching frequency of the converter should increase. However, higher frequency operation results in higher switching losses that reduce the converter efficiency. Therefore, soft-switching techniques are required to eliminate switching losses of the converter. Several

topologies and control schemes have been presented in recent years for various applications to improve the efficiency and reliability of microinverters [3]-[9]. A non-isolated single-phase ZVS inverter is introduced in [4], in which an auxiliary resonant circuit is utilized to provide soft-switching conditions. However, isolated structures are more suitable for PV applications when amplification and galvanic isolation is needed. Therefore, some researchers have introduced Flyback-based microinverters to provide both isolation and amplification, as well as single-stage operation [5]-[6]. However, these types of microinverters utilize auxiliary circuits to provide soft-switching for the converter switches, which complicate the control system and restrain the converter's performance for higher frequencies. Some others have proposed dual active bridge (DAB) based microinverters with no auxiliary circuits, to provide soft-switching operation and high efficiency in high-power applications [7]-[8]. Even though the auxiliary circuits are not employed in [8], a high number of components are utilized due to its two-stage configuration, which leads to more cost and volume, and more complex control designs. Thus, single-stage topologies are preferred in PV applications due to their lower power losses and lower number of components. A single-stage DAB-based microinverter is presented in [9], in which a sinusoidal modulation is combined with the phase shift modulation of the DAB structure to provide soft-switching conditions. However, the control scheme of the presented microinverter is still complex to provide soft-switching operation for a wide range of input voltage and output load

[0005] Accordingly, there exists a need for a single-stage single-phase microinverter with a fully soft-switching operation for a wide range of input voltage and output load. There further exists a need for such a microinverter that utilizes a low number of components with a simple control strategy, which results in a low-cost and low-volume microinverter for high-frequency and highly efficient applications.

SUMMARY OF THE INVENTION

[0006] The present invention provides a Beat Frequency Modulation (BFM) system for generating a low frequency reference waveform. The BFM system includes two or more converters, a frequency control module, and a rectifier. The two or more converters are connected in series or parallel or cascaded. Each converter includes at least a power switch configured to generate a high frequency power signal controlled by BFM modules at their respective outputs. The frequency control module is configured to operate a BFM carrier signal of each of the converters at different frequencies, thereby creating an envelope of a resulting signal containing a desired low frequency reference signal. The rectifier is connected to outputs of the converters, the rectifier configured to rectify the high frequency signal with the low frequency envelope shape, thereby generating a low frequency sinusoidal waveform.

[0007] The present invention additionally provides a microinverter for use with a photovoltaic (PV) system. The microinverter includes an LC resonant tank and a magnetizing inductance L_m electrically connected to the LC resonant tank, wherein the LC resonant tank and the magnetizing inductance L_m form an LLC resonant network. The LC resonant tank includes a first resonant LC converter configured to generate a first current having a frequency of a sinusoidal current of F_0 ; a second resonant LC converter configured to generate a second current having a frequency of a sinusoidal current of F_0+2F_g , where f_0 is the switching frequency of the first resonant LC converter and f_g is a grid frequency; and a first switching leg associated with the first resonant LC converter and a second switching leg associated with the second resonant LC converter, the first switching leg and the second switching leg configured to merge the first resonant LC converter and the second resonant LC converter using beat frequency modulation (BFM).

[0008] The present invention additionally provides a method of operating a photovoltaic that includes electrically coupling the photovoltaic to the inventive microinverter disclosed herein.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] The present invention is further detailed with respect to the following drawings that are

intended to show certain aspects of the present of invention, but should not be construed as limit on the practice of the invention, wherein:

[0010] FIG. 1 shows a the beat frequency modulation (BFM) method according to embodiments of the present invention;

[0011] FIG. 2 shows a converter topology derivation according to embodiments of the present invention;

[0012] FIG. 3 shows a BFM microinverter configuration according to embodiments of the present invention;

[0013] FIG. 4A is a graph showing resonant LLC tank gain versus normalized switching frequency for different quality factors;

[0014] FIG. 4B is a block diagram showing an equivalent resonant circuit according to embodiments of the present invention;

[0015] FIG 5 is a block diagram of the microinverter control strategy according to embodiments of the present invention;

[0016] FIG. 6 is a block diagram of a modulation unit in the control scheme according to embodiments of the present invention;

[0017] FIG. 7 show a PWM generation unit in the control scheme according to embodiments of the present invention;

[0018] FIG. 8A is a graph showing simulation results for voltage and current of the grid of the inventive BFM microinverter;

[0019] FIG. 8B is a graph showing simulation results for voltage and current across the resonant tank of the inventive BFM microinverter;

[0020] FIG. 8C is a graph showing simulation results for resonant tank current over grid periods of the inventive BFM microinverter;

[0021] FIG. 8D is a graph showing simulation results for voltage waveforms of the input stage and output stage switches of the inventive BFM microinverter;

[0022] FIG. 8E is a graph showing simulation results for inverter current over grid periods of the inventive BFM microinverter;

[0023] FIG. 8F is a graph showing simulation results for current waveforms of the input stage and output stage switches of the inventive BFM microinverter;

[0024] FIG. 9A shows experimental results of the inventive BFM microinverter with resonant current I_r : 60Hz envelope along with a zoom scale for 100kHz component;

[0025] FIG. 9B shows experimental results of the inventive BFM microinverter with voltage and current across resonant tank (soft-switching conditions are provided due to inductive current);

[0026] FIG. 10 shows experimental results of the inventive BFM microinverter with Voltage and current waveforms of the grid;

[0027] FIG. 11 shows using BFM single-stage microinverter configuration with a half-bridge structure at the grid side;

[0028] FIG. 12 shows an exemplary inventive PWM generation unit if reactive power control is desired; and

[0029] FIG. 13 shows an exemplary inventive control block diagram implementation of the microinverter.

DETAILED DESCRIPTION OF THE INVENTION

[0030] The present invention has utility as a single-stage single-phase microinverter with a fully soft-switching operation for a wide range of input voltage and output load as a result of a new beat frequency modulation (BFM) which can be utilized in different topologies. The BFM microinverter has additional utility in that it utilizes a low number of components with a simple control strategy, which results in a low-cost and low-volume microinverter for high-frequency and highly efficient applications. According to embodiments, the inventive BFM is combined with the LLC-based microinverter, in which soft-switching conditions for all semiconductors are provided for a wide range with no auxiliary circuit. A simple single-phase DQ current controller is employed to regulate the output current.

[0031] It is to be understood that in instances where a range of values are provided that the range is intended to encompass not only the end point values of the range but also intermediate values of the range as explicitly being included within the range and varying by the last significant figure of the range. By way of example, a recited range of from 1 to 4 is intended to include 1-2, 1-3, 2-4, 3-4, and 1-4.

[0032] According to embodiments, beat frequency modulation (BFM) is illustrated in FIG. 1. Mathematically, the summation of two high-frequency sinusoidal waveforms with two different frequencies (such that the frequency difference between the two waveforms is considerably lower than the frequency of each waveform) would result in a high-frequency sinusoidal waveform with a low-frequency envelope as can be seen in Equation 1.

$$y = \sin(\omega_1 t) + \sin(\omega_2 t) = 2 \sin\left(\frac{\omega_1 + \omega_2}{2} t\right) \cos\left(\frac{\omega_1 - \omega_2}{2} t\right)$$

Equation 1:

[0033] Assuming that the frequency difference is equal to twice the grid frequency (e.g., 120 Hz), the resulting envelope would be a 60 Hz sinusoidal waveform. Therefore, the inventive

microinverter is obtained by combining two high-frequency sinusoidal waveforms using two series resonant converters as shown in FIG. 2. The frequencies of sinusoidal currents generated by the two series resonant LC converters are f_0 and f_0+2f_g , where f_0 is the switching frequency of the converter and f_g is the grid frequency. The switching frequency is a little higher than the resonance frequency of the LC networks to provide zero voltage switching (ZVS) conditions for the main converter switches. Then, two LC networks can be merged through two switching legs with the above-mentioned frequency operation, resulting in the desired high-frequency waveform with the grid-frequency envelope.

[0034] FIG. 3 shows an embodiment of the inventive BFM microinverter. As can be observed, the inventive microinverter is configured based on the LLC resonant network in which the magnetizing inductance L_m is added to the previous LC series resonant tank to provide a wider softswitching range for a wide input voltage range suitable for PV applications. The proposed BFM is applied to the LLC network using two switching legs. At the output stage, the conventional diode bridge rectifier and full bridge unfold are merged to reduce the number of semiconductor components which results in a single-stage single-phase microinverter configuration. Eventually, utilizing a capacitor at the output, the envelope of the inverter current (i_{inv}) is provided to the connected grid or output load. As a result, a grid-frequency sinusoidal waveform is injected to the connected grid.

[0035] The resonant LLC tank of embodiments of the inventive microinverter is designed similar to DC-DC resonant converters with fundamental harmonic approximation (FHA). The resonant tank gain in Equation 2 is derived by analyzing its equivalent circuit shown in FIG. 4B. The gain diagram of the LLC resonant tank versus normalized switching frequency f_n for different quality factors $Q=\omega_r L_r/R_{ac}$ is shown in FIG. 4A. According to the required minimum and maximum DC gain of the converter ($V_{in}=20\sim 40V$, $V_{out}=340V$), a suitable value for inductance ratio $m=(L_r+L_m)/L_r$ is selected. Then based on the maximum output power

($P_{out}=250W$), a maximum quality factor is selected such that the inventive microinverter can operate in a reasonable frequency range to provide the required gain at the inductive ZVS region. Therefore, the inductive region operation is ensured for the whole range of input voltage and output power. Then, the resonant components are obtained solving Equations 2-7.

$$G = \left| \frac{V_{out}}{V_{in}} \right| = \frac{f_c^2 (m-1)}{\sqrt{(mf_c^2 - 1)^2 + f_c^2 (f_c^2 - 1)^2 (m-1)^2 Q^2}}$$

Equation 2:

$$Q = \frac{\sqrt{\frac{L_r}{C_r}}}{R_{eq}}$$

Equation 3:

$$R_{eq} = \frac{8}{\pi^2} \frac{N_p^2}{N_s^2} R_c$$

Equation 4:

$$f_n = \frac{f_s}{f_r}$$

Equation 5:

$$f_r = \frac{1}{2\pi\sqrt{L_r C_r}}$$

Equation 6:

$$m = \frac{I_{L_1} + I_{L_{m1}}}{I_{L_1}}$$

Equation 7:

[0036] The utilized values in the design of the inventive microinverter are obtained as $N=12$, $f_r=100\text{kHz}$, $G_{\max}=1.6$, $G_{\min}=0.8$, $Q_{\max}=0.4$, $m=7$, $C_r=1.25\mu\text{F}$, $L_r=2\mu\text{H}$ and $L_m=12\mu\text{H}$.

[0037] Considering the aforementioned conditions for the LLC resonant tank, the fully soft-switching operation is provided for embodiments of the inventive microinverter switches. The S_1 - S_2 leg is switched in complementary mode with a PWM signal in which the duty cycle is %50, and the frequency is equal to f_0+2f_g . A suitable dead time is considered for the switches to provide soft-switching operation. A similar PWM signal with a frequency equal to f_0 is applied to the S_3 - S_4 leg. Therefore, the S_1 - S_4 switches are turned on at zero voltage zero current switching (ZVZCS) condition. In addition, ZVS turn-off conditions are provided for S_1 - S_4 due to the snubber capacitors across these switches. The output stage switches S_5 - S_8 are switched according to the positive and negative half cycles of the output voltage. In the positive half cycle of the output voltage (grid frequency cycle), S_5 and S_6 are on, and the body diodes of the S_7 and S_8 are conducting at ZCS conditions according to the current direction of the transformer. Therefore, S_7 and S_8 can be turned on in synchronous with their body diodes to reduce the conduction losses. The ZCS conditions are provided for both turn-on and turn-off instants of the S_5 and S_6 . For the negative half cycle, S_7 and S_8 are on, and the body diodes of the S_5 and S_6 are conducting at ZCS conditions. Similar to the positive half cycle, switches can be turned on in synchronous with their body diodes, and ZCS conditions are provided for S_7 and S_8 .

[0038] The grid-connected control scheme of the inventive microinverter is shown in FIG. 5. As can be seen, to regulate the output current of the inventive microinverter, a single-phase DQ current controller is utilized in which an orthogonal signal generation (OSG) technique is

used to provide a virtual orthogonal component of the grid current in $\alpha\beta$ frame [10]. In this method, the OSG unit generates the β component of the grid current which is a 90-degree delayed version of that signal. The utilized OSG unit makes the controller more stable due to independence of system parameters and operating frequency. Furthermore, the employed OSG does not produce any additional delay to the controller.

[0039] The output current of the microinverter (i_o) is synchronized with the grid voltage through a phase-locked loop (PLL) unit. As a result, the grid frequency f_g , and grid angle θ_g along with the D component of the grid voltage v_{gd} are obtained from the PLL unit. These values are used as references for the PWM unit to synchronize the output current of the microinverter with the grid voltage. The DQ frame references of the current controller are calculated according to desired output power calculations. Then, a simple PI controller is employed in both D and Q axes of the currents to regulate the DQ components of the current. The PI controller is designed based on the simplified system model of the converter. Considering a non-ideal inductor filter (L_g in series with R_g) as the plant in the system model of the proposed microinverter, the k_p and k_i of the PI are selected such that the open-loop plant pole $s = -R_g/L_g$ are canceled by the compensator zero $s = -k_i/k_p$. As can be seen in the block diagram of the control system in FIG. 5, to eliminate the coupling effect of the DQ axes in the converter, decoupling terms are added in the control system.

[0040] The inventive beat frequency modulation and PWM generation units are illustrated in FIGS. 6 and 7, respectively. As can be observed, the switching frequency (f_o) and phase angle (ϕ) of the microinverter are obtained from DQ components generated by the current controller according to the relationships between the phase and amplitude, and DQ terms in a single-phase system. The current amplitude at the output is changed by adjusting f_o which is applied directly to the LLC resonant tank. By changing the switching frequency, the voltage gain of the resonant tank is changed, and thus, the desired amplitude of the current at the output

is obtained. Also, the phase angle of the output current is changed by adjusting the phase shift between the two switching legs at the input stage of the inventive microinverter.

[0041] The beat frequency modulation (BFM) method of the present invention is applied to different power converters to obtain a BFM microinverter with a fully soft-switching operation. The inventive BFM microinverter is presented based on the LLC resonant converter, in which soft-switching conditions are provided for all switches. The inverter and rectifier of the microinverter are merged to obtain a single-stage single-phase structure. The control strategy of the BFM microinverter is based on the single-phase DQ frame current control. Modulation and PWM generation units employed in the control scheme are illustrated. The design of LLC resonant components is discussed. Simulation results are displayed to show the soft-switching operation and BFM method operation.

[0042] **Simulation and Experimental Results**

[0043] The simulation results of embodiments of the inventive BFM microinverter are displayed in FIGS. 8A-8F. The inventive microinverter is designed for an input voltage $V_{in}=20\sim 40V$, an output voltage $V_{out}=240V_{rms}$, a nominal switching frequency $f_{sw}=100kHz$, and a maximum output power $P_{out}=250W$. The voltage and current of the grid are shown in FIG. 8A. The voltage and current across the resonant tank are shown in FIG. 8B. As can be seen, the current is inductive, and thus, the soft-switching condition is provided. In FIG. 8C, the resonant tank current is displayed over grid periods. The voltage and current waveforms of the input stage and output stage switches are shown in FIG. 8D and FIG. 8E, in which soft-switching conditions are provided for both turn-on and turn-off instants. To confirm the theoretical analysis, experimental results are shown in FIG. 9A and FIG. 10 in which the functionality and validity of the inventive BFM method are shown.

[0044] FIG. 11 shows an inventive BFM microinverter in which a four-quadrant half-bridge with two output capacitors are utilized to replace the three-winding transformer by a two-

winding transformer. This structure has some advantages over three-winding structure as it eliminates the spikes caused by leakage current and employs the transformer magnetization properly.

[0045] FIG. 12 shows a PWM generation unit of the inventive microinverter in which the secondary side switches (S5-S8) are required to be switched with a high frequency PWM with the carrier frequency of $f_o + f_g$ and the phase of $\phi + \theta_s$ to provide none-unity power factors of the output current. The phase shift between primary side and secondary side (θ_s) is obtained from series resonant converter design based on the LBT where the resonant tank current becomes zero in a resonant period. The value of θ_s is constant during a line cycle and it can be updated based on the output power and quality factor of the resonant tank. The switching frequency f_o and the carrier phase ϕ are obtained from the modulation unit in which the U_d and U_q of the current controller are converted to the amplitude and phase of the output current using the DQ equations. The amplitude and phase of the output current are determined by the switching frequency and the phase obtained from modulation unit, respectively.

[0046] FIG. 13 shows an microinverter control system is shown in Fig. 13 in which the PI controllers and state feedbacks ($U = -KX$) are designed by the linear quadratic tracking (LQT). FIG. 13 provides more details about the design of the current controller shown in FIG. 5.

[0047] **References**

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[0048] While at least one exemplary embodiment has been presented in the foregoing description and attached appendix, it should be appreciated that a vast number of variations exist. It should also be appreciated that the exemplary embodiment or exemplary embodiments are only examples, and are not intended to limit the scope, applicability, or configuration of the described embodiments in any way. Rather, the foregoing description and incorporated references will provide those skilled in the art with a convenient roadmap for implementing the exemplary embodiment or exemplary embodiments. It should be understood that various changes may be made in the function and arrangement of elements without departing from the scope as set forth in the appended claims and the legal equivalents thereof.

CLAIMS

1. A Beat Frequency Modulation (BFM) system for generating a low frequency reference waveform, the system comprising:

two or more converters connected in series or parallel or cascaded, each converter comprising at least a power switch configured to generate a high frequency power signal controlled by BFM modules at their respective outputs;

a frequency control module configured to operate a BFM carrier signal of each of the converters at different frequencies, thereby creating an envelope of a resulting signal containing a desired low frequency reference signal; and

a rectifier connected to outputs of the converters, the rectifier configured to rectify the high frequency signal with the low frequency envelope shape, thereby generating a low frequency sinusoidal waveform.

2. A microinverter for use with a photovoltaic (PV) system, the microinverter comprising:

a LC resonant tank comprising:

a first resonant LC converter configured to generate a first current having a frequency of a sinusoidal current of F_0 ;

a second resonant LC converter configured to generate a second current having a frequency of a sinusoidal current of F_0+2F_g , where f_0 is the switching frequency of the first resonant LC converter and f_g is a grid frequency; and

a first switching leg associated with the first resonant LC converter and a second switching leg associated with the second resonant LC converter, the first switching leg and the second switching leg configured to merge the first resonant LC converter and the second resonant LC converter using beat frequency modulation (BFM); and

a magnetizing inductance L_m electrically connected to the LC resonant tank;

wherein the LC resonant tank and the magnetizing inductance L_m form an LLC resonant network.

3. The microinverter of claim 2 further comprising an output stage electrically connected to the LLC resonant network.

4. The microinverter of claim 3 wherein the output stage comprises a diode bridge rectifier, a full bridge unfolded, and a capacitor.

5. The microinverter of claim 4 wherein the diode bridge rectifier and the full bridge unfolded are merged into a single component.

6. The microinverter of claim 2 wherein the first resonant LC converter and the second resonant LC converter are arranged in series.

7. The microinverter of claim 2 wherein the switching frequency F_0 is greater than a resonance frequency of the first LC converter and the second LC converter.

8. The microinverter of claim 2 wherein BFM comprises summing a first waveform of the sinusoidal current of the first current and a second waveform of the sinusoidal current of the second current to obtain a high-frequency sinusoidal waveform with a low-frequency using the following equation:

$$y = \sin(\omega_1 t) + \sin(\omega_2 t) = 2 \sin\left(\frac{\omega_1 + \omega_2}{2} t\right) \cos\left(\frac{\omega_1 - \omega_2}{2} t\right)$$

9. The microinverter of claim 8 wherein a frequency difference between the first waveform and the second waveform is lower than the frequency of each of the first waveform and the second waveform independently.

10. The microinverter of claim 2 wherein the magnetizing inductance L_m is configured to provide a wider soft-switching range for a wide input voltage range suitable for PV applications.

11. The microinverter of claim 2 wherein the microinverter is a single-stage microinverter.

12. The microinverter of claim 2 wherein the microinverter is a single-phase microinverter.

13. The microinverter of claim 2 wherein the microinverter has a soft-switching operation for a wide range of input voltage and output load.

14. A method of operating a photovoltaic comprising:

electrically coupling the photovoltaic to a microinverter of any one of claims 2 to 13.

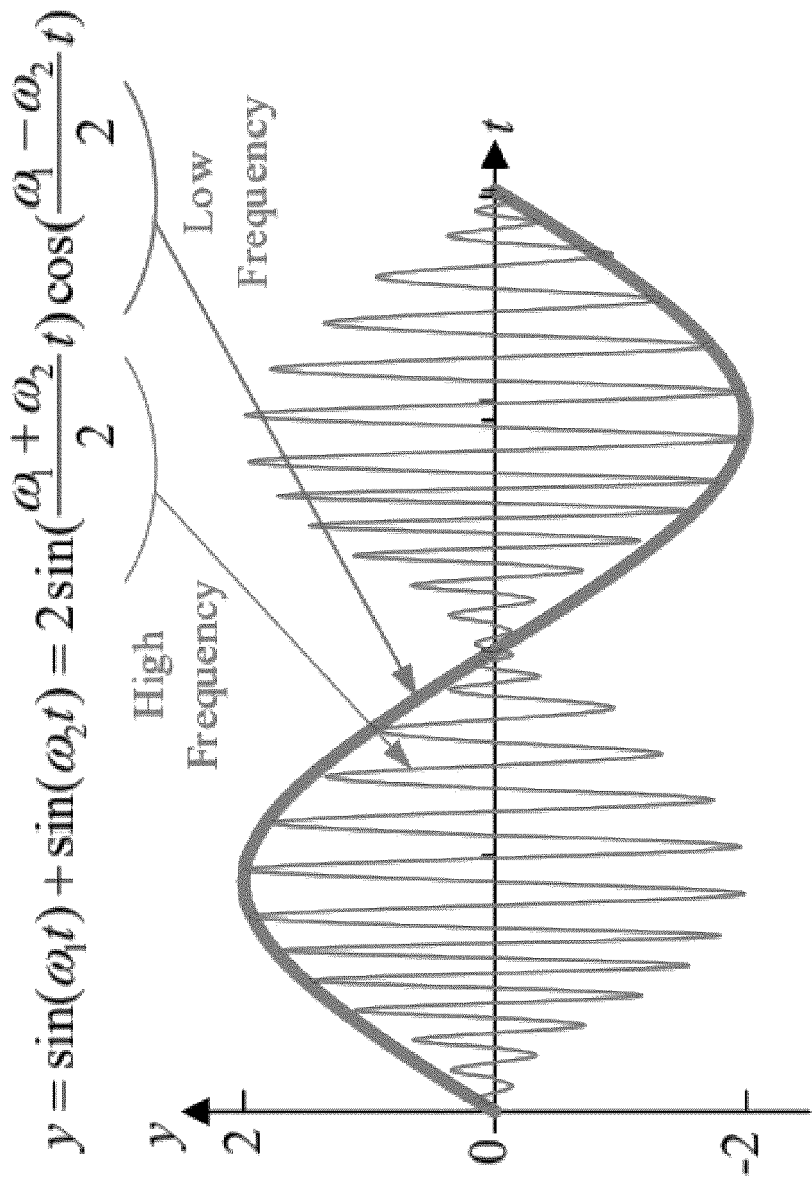


FIG. 1

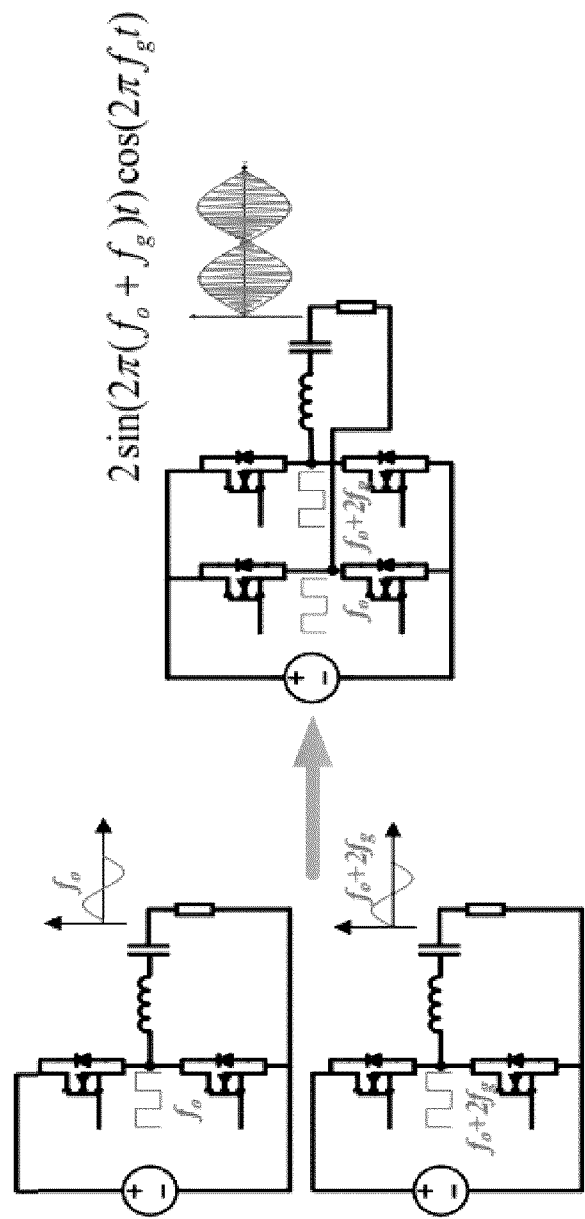


FIG. 2

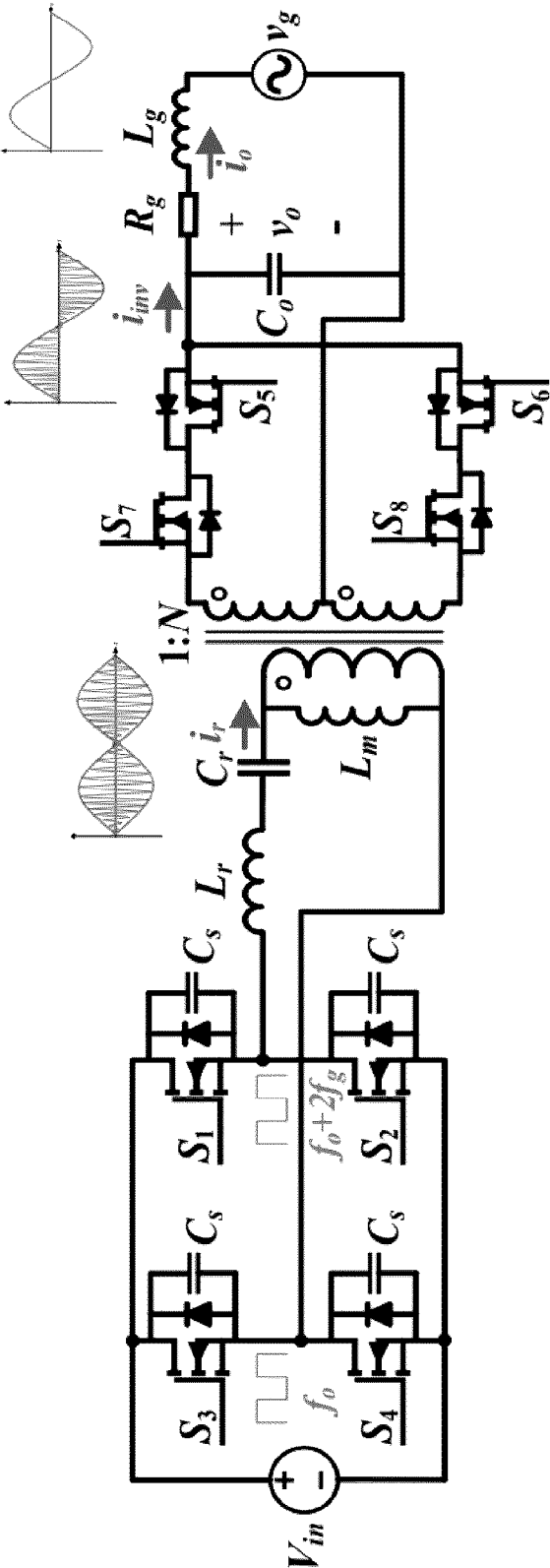


FIG. 3

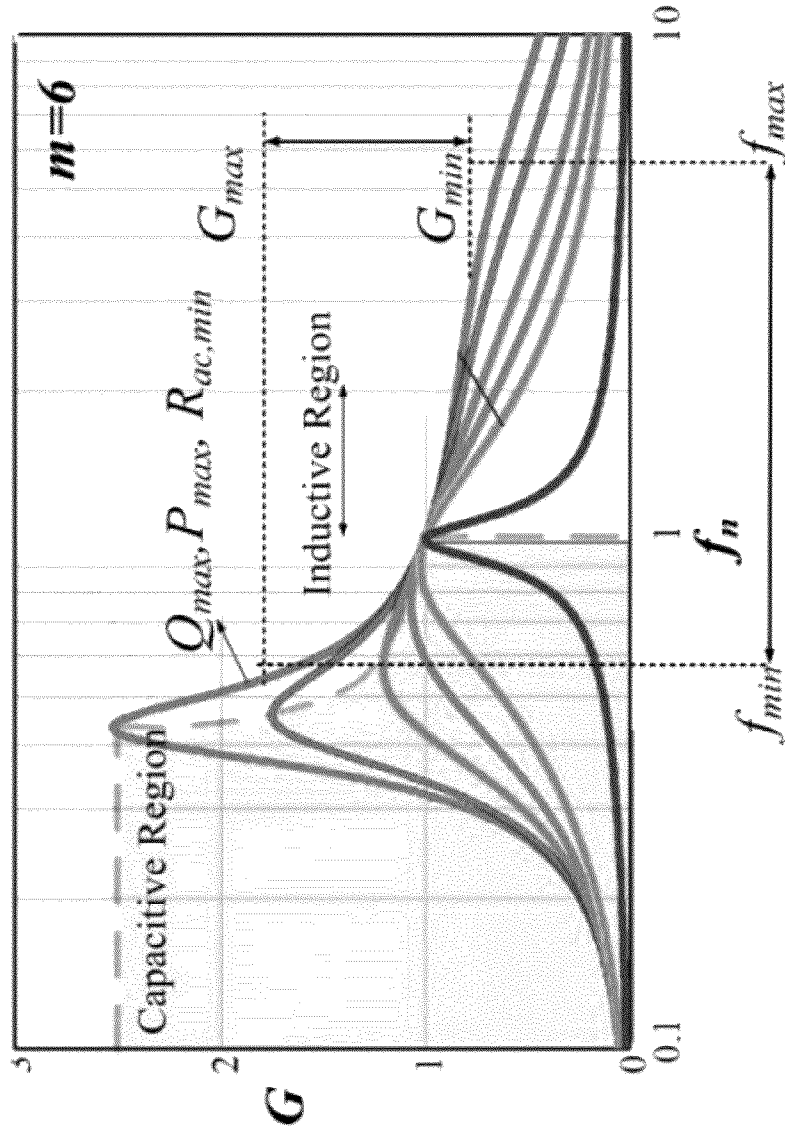


FIG. 4A

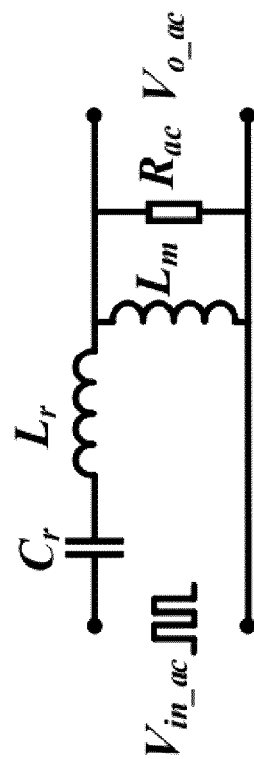


FIG. 4B

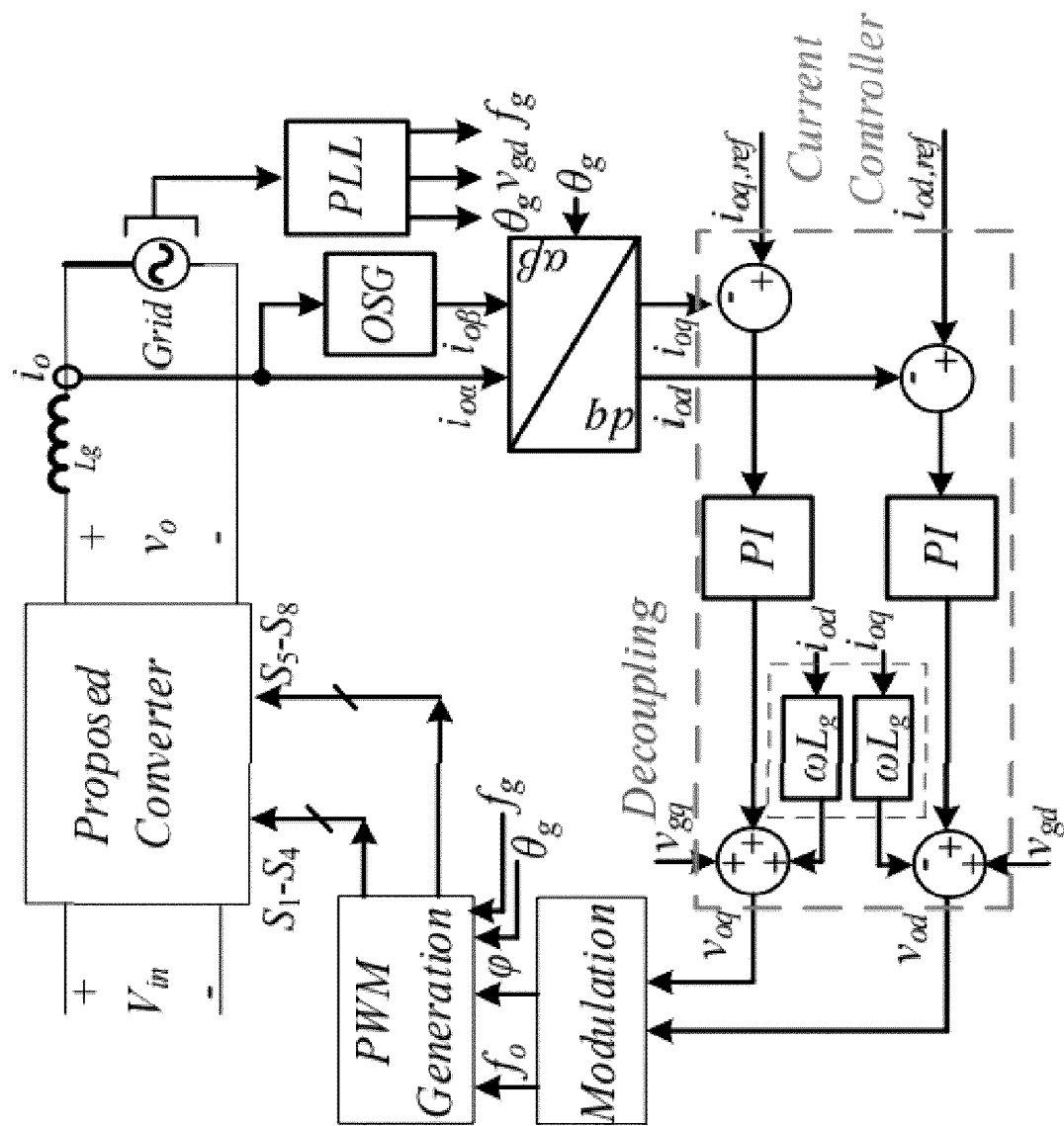


FIG. 5

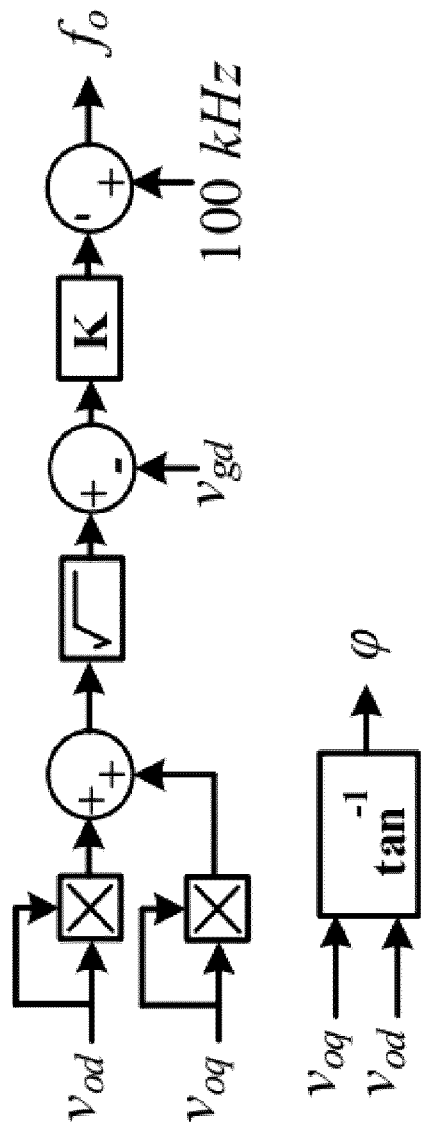


FIG. 6

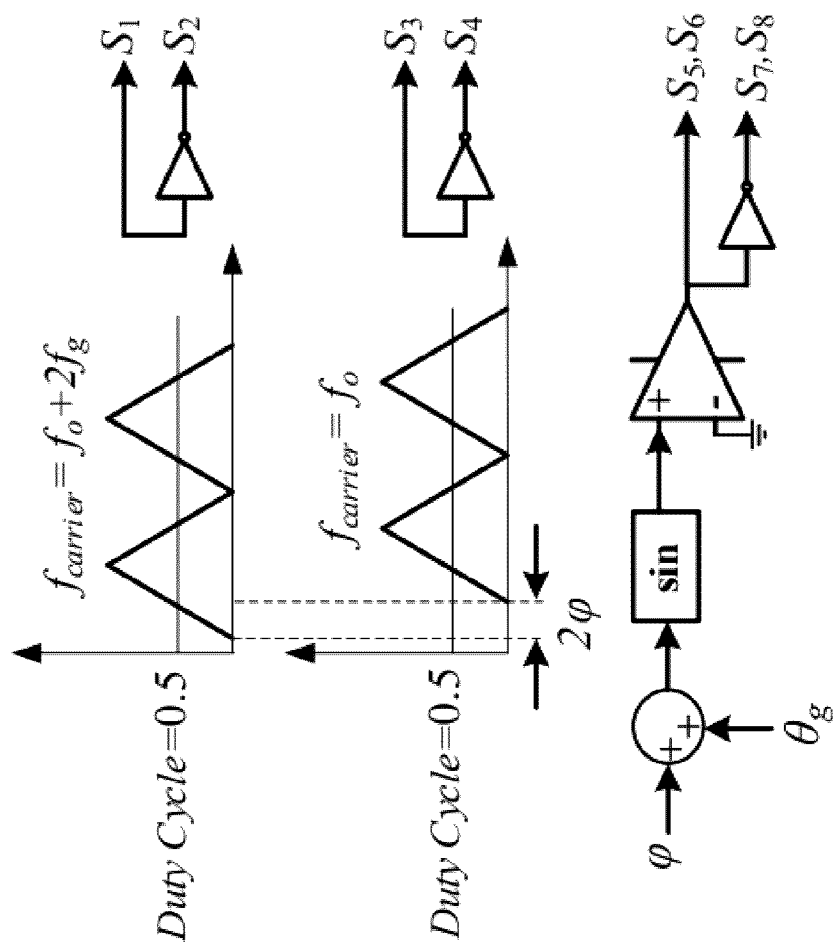


FIG. 7

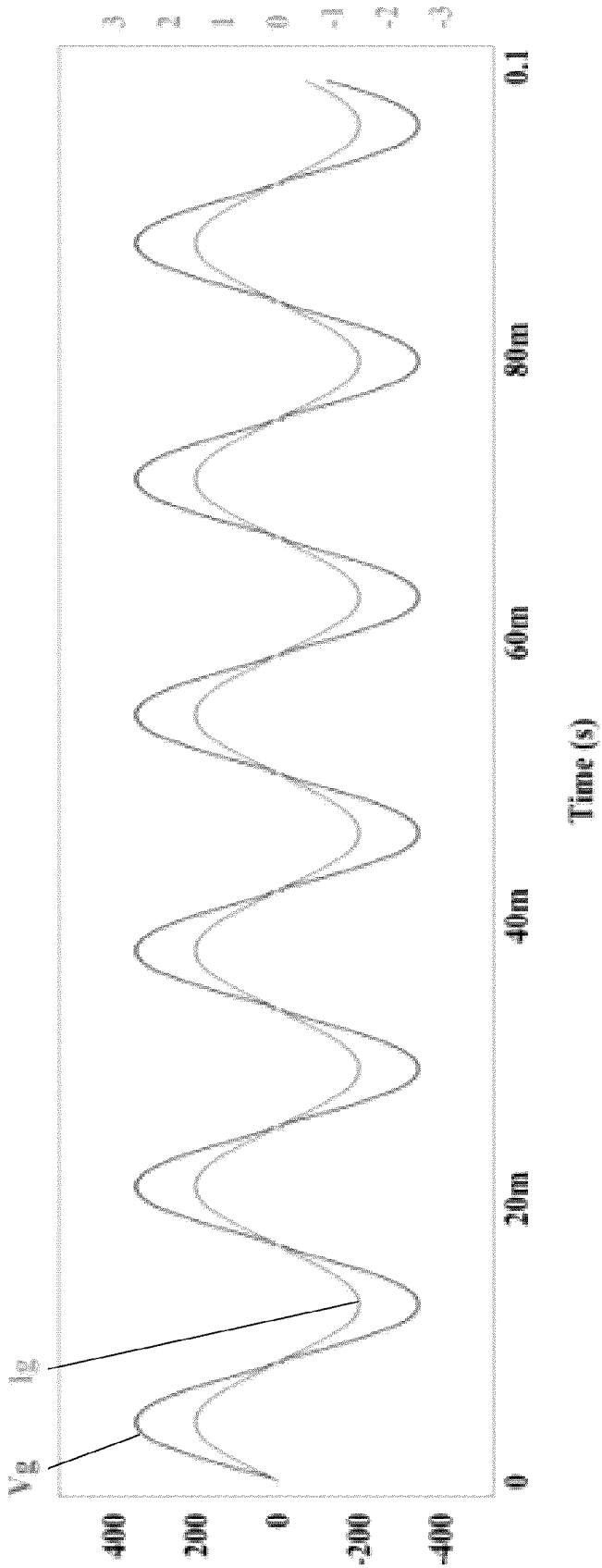


FIG. 8A

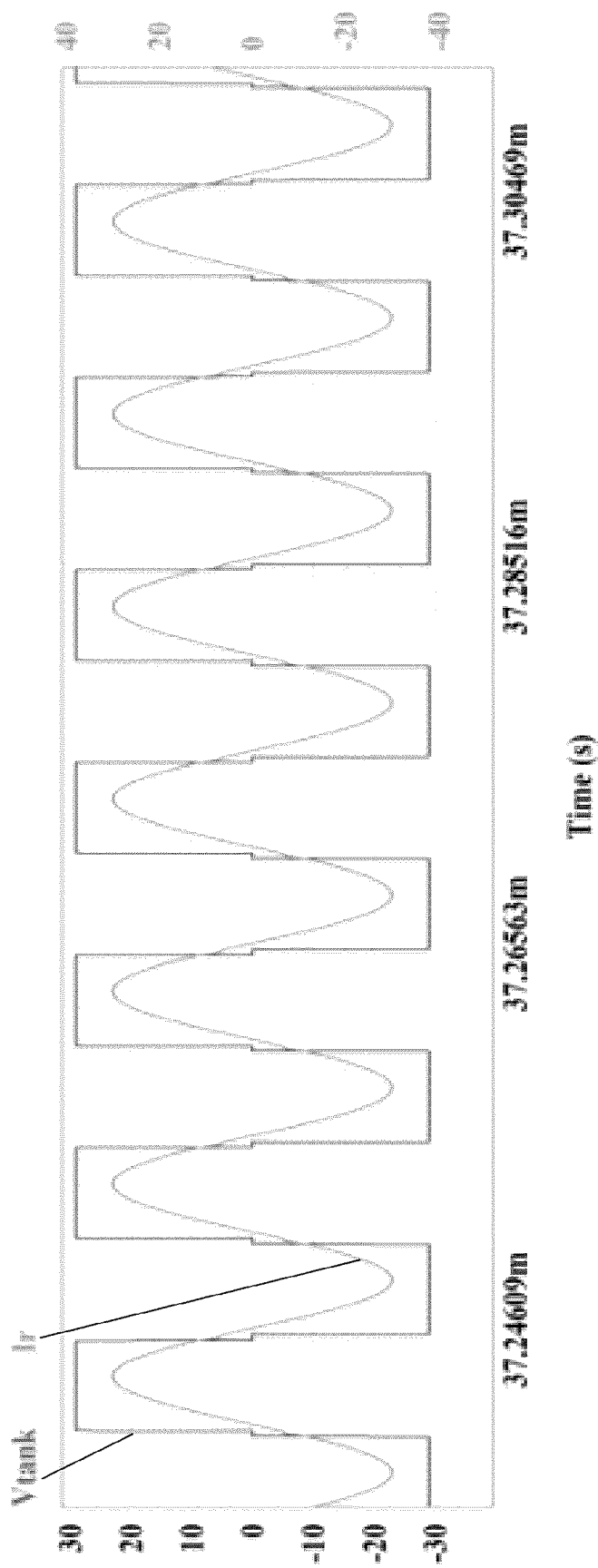


FIG. 8B

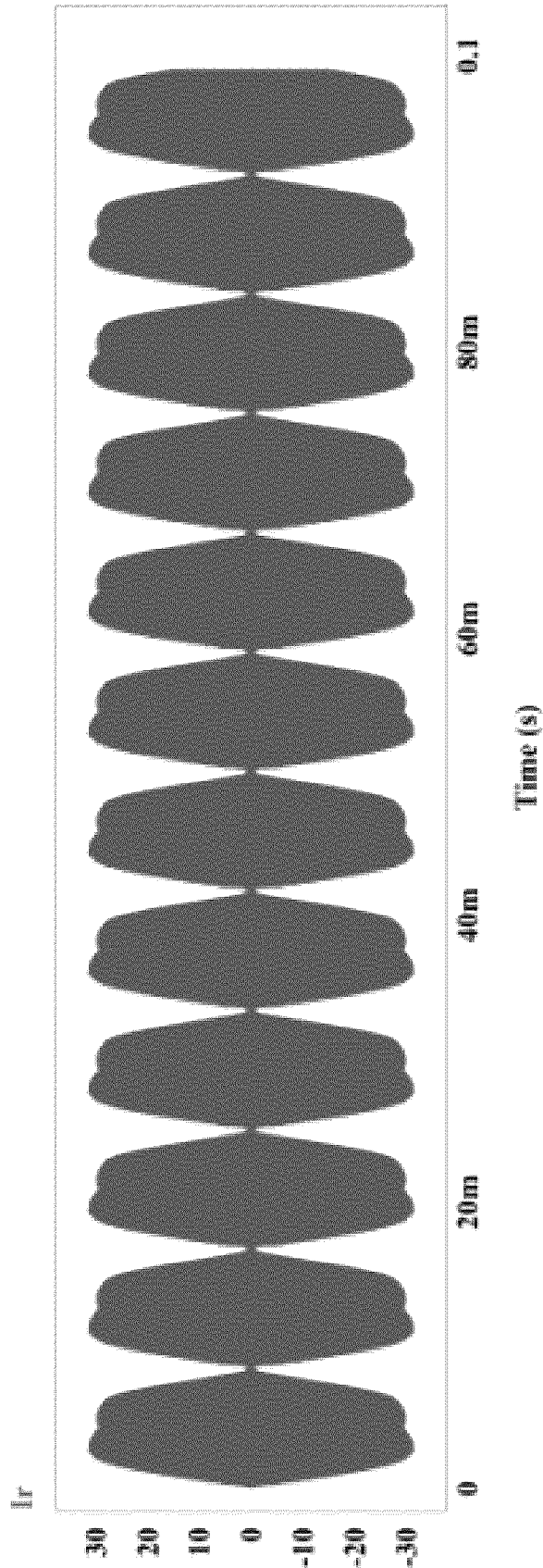


FIG. 8C

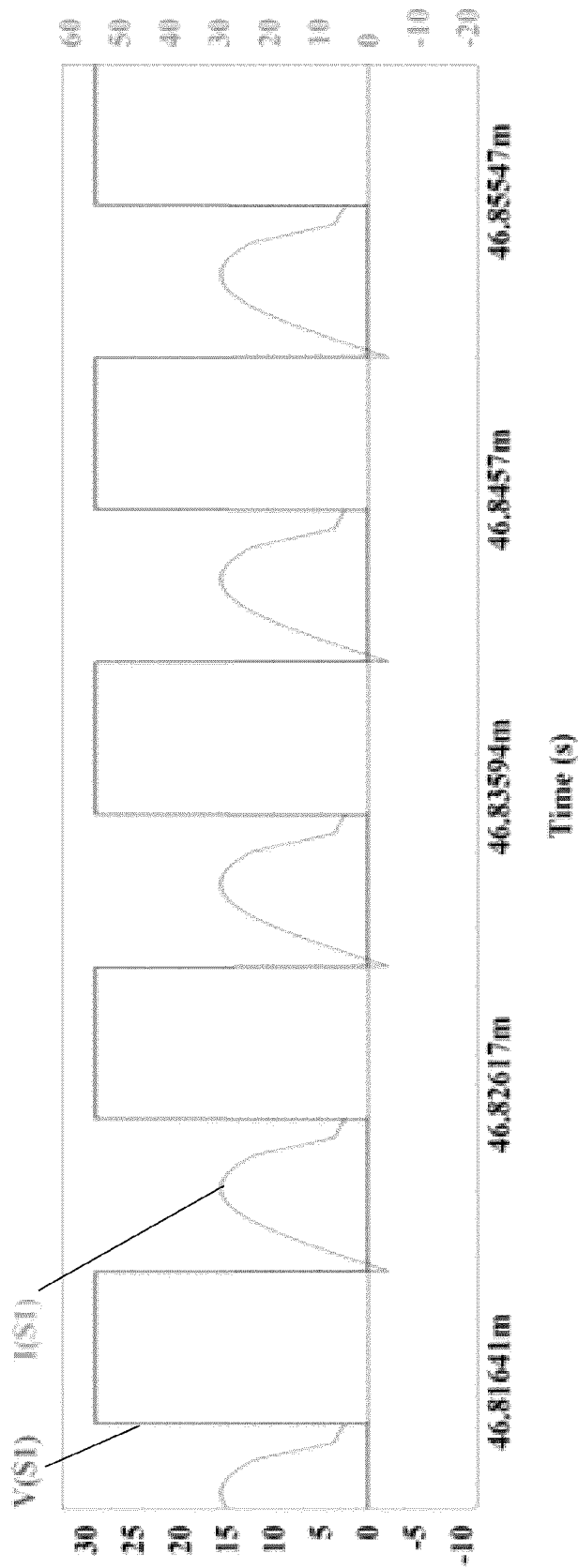


FIG. 8D

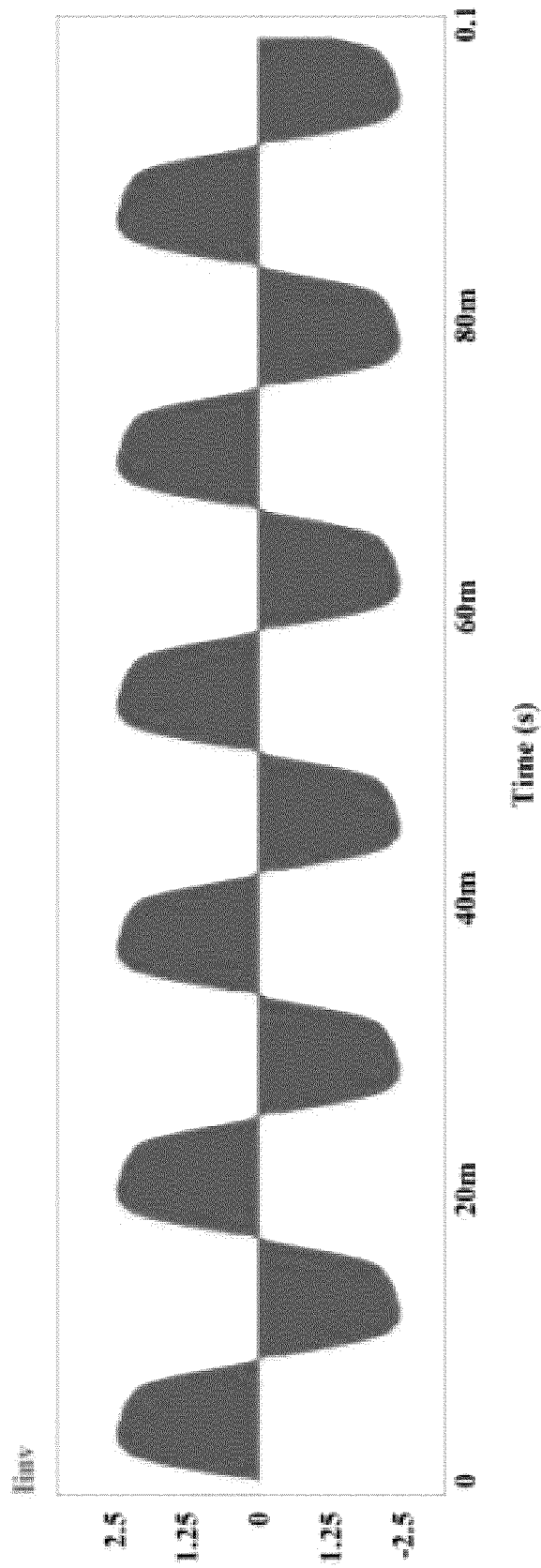


FIG. 8E

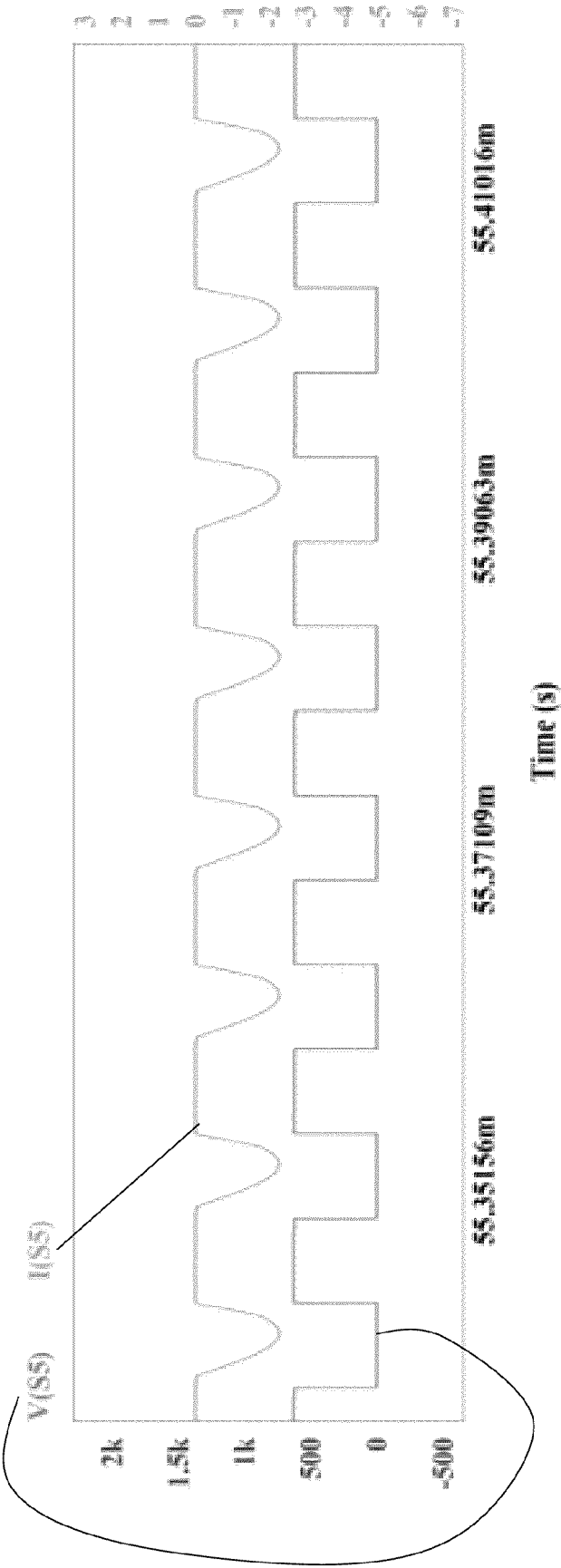


FIG. 8F

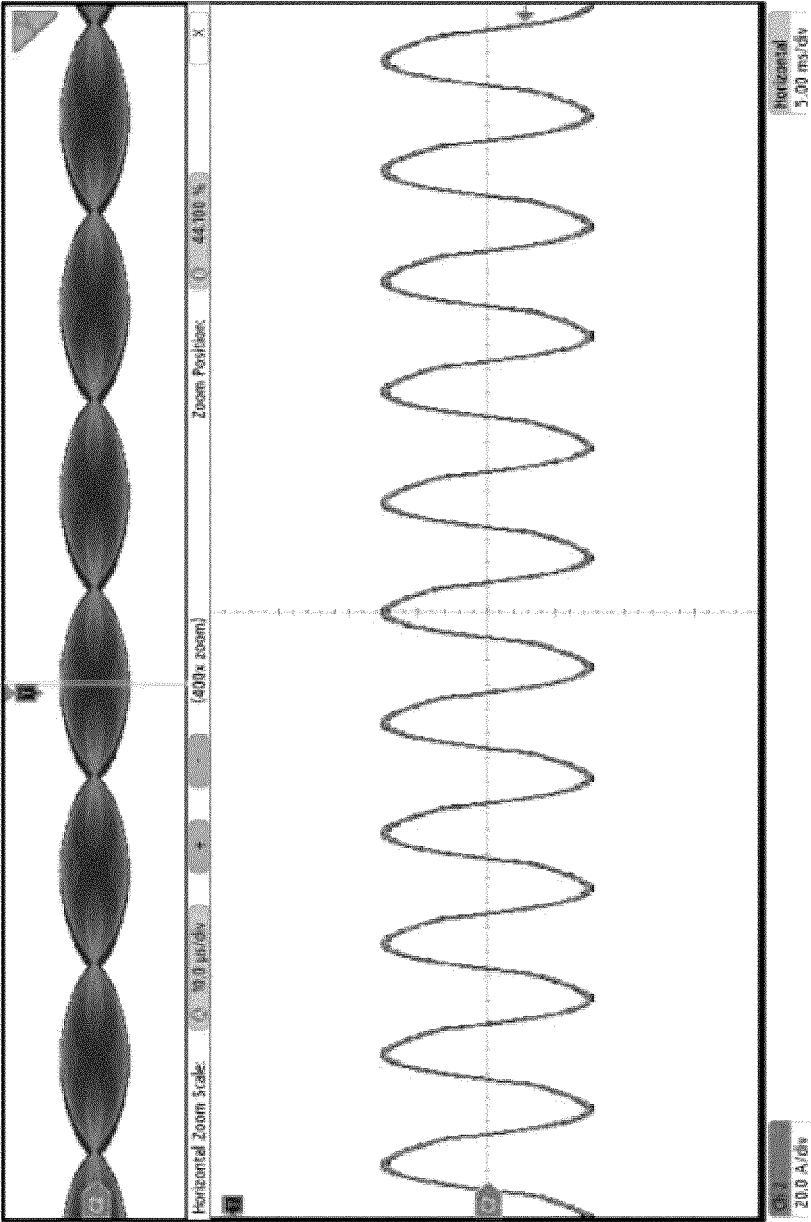


FIG. 9A

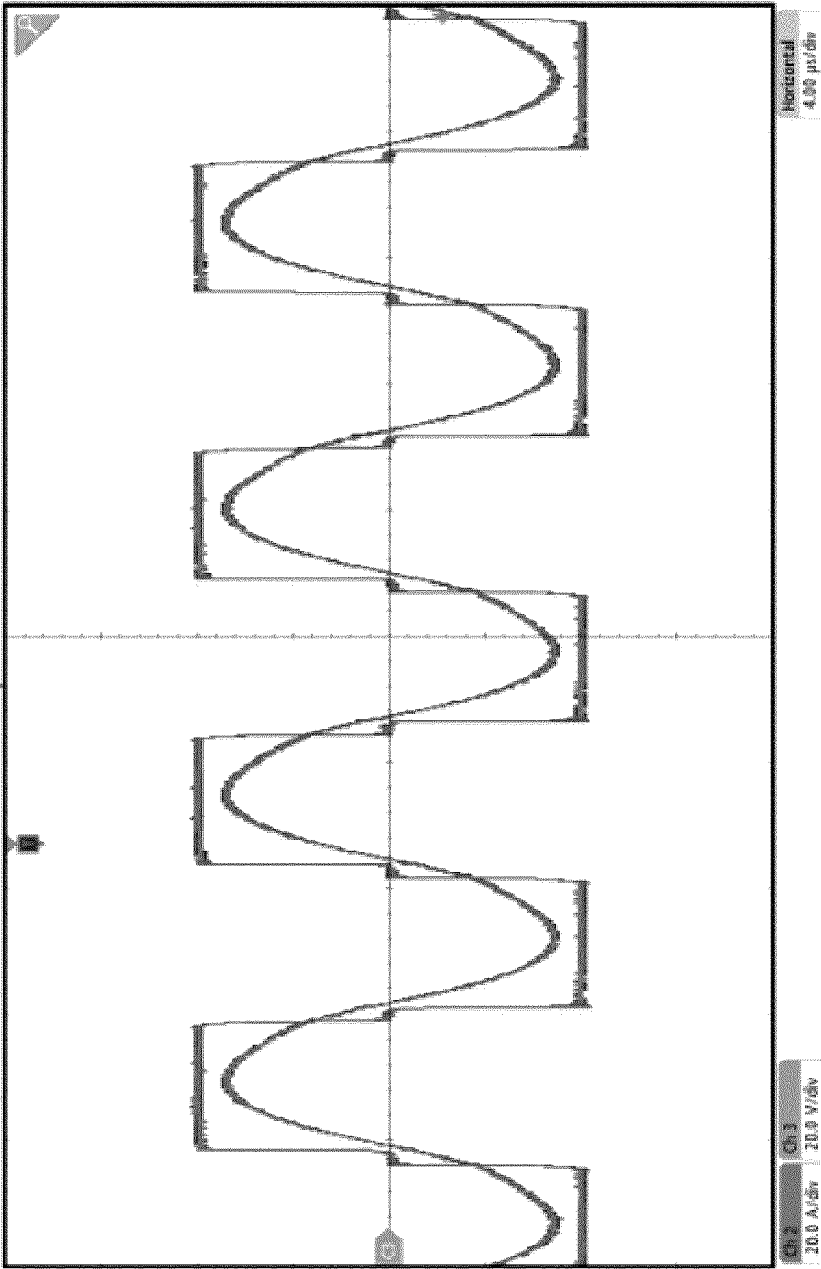


FIG. 9B

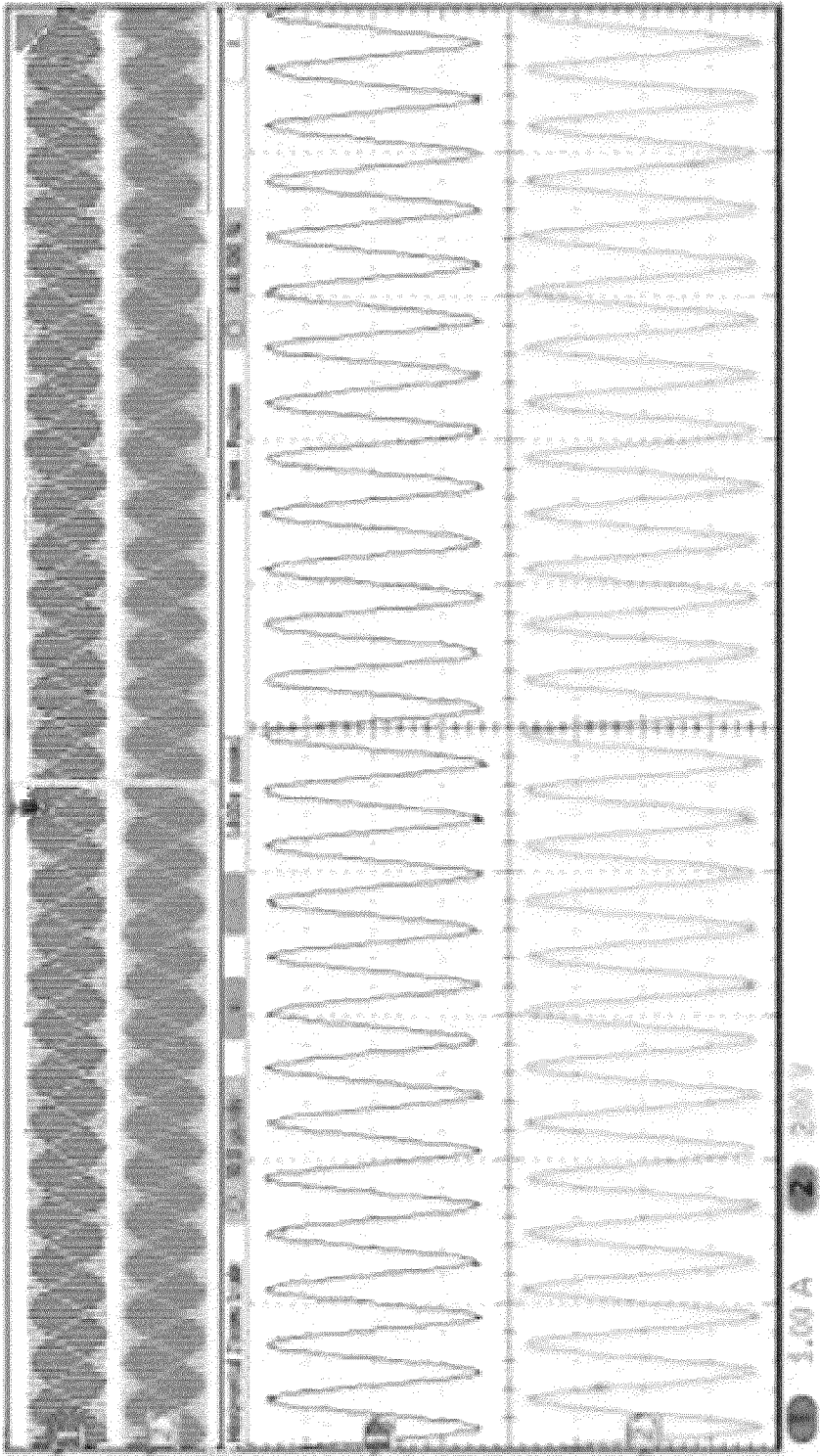


FIG. 10

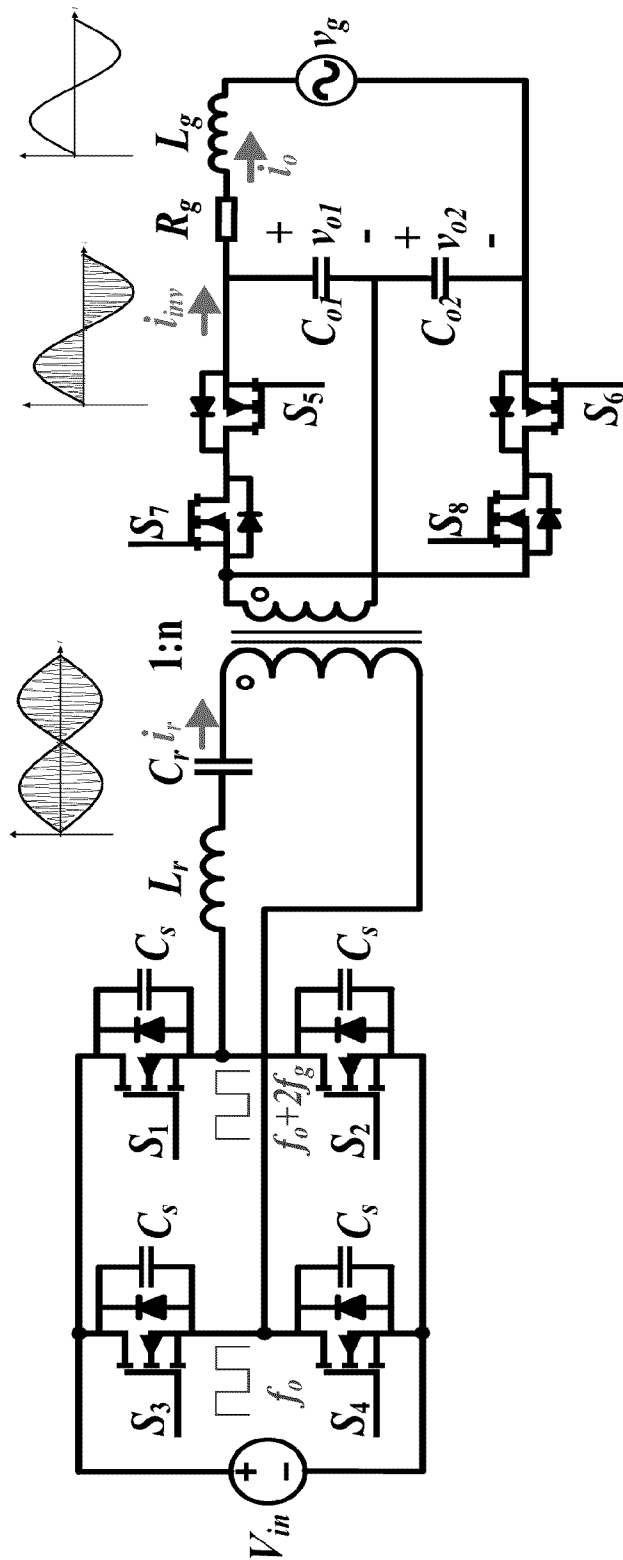


FIG. 11

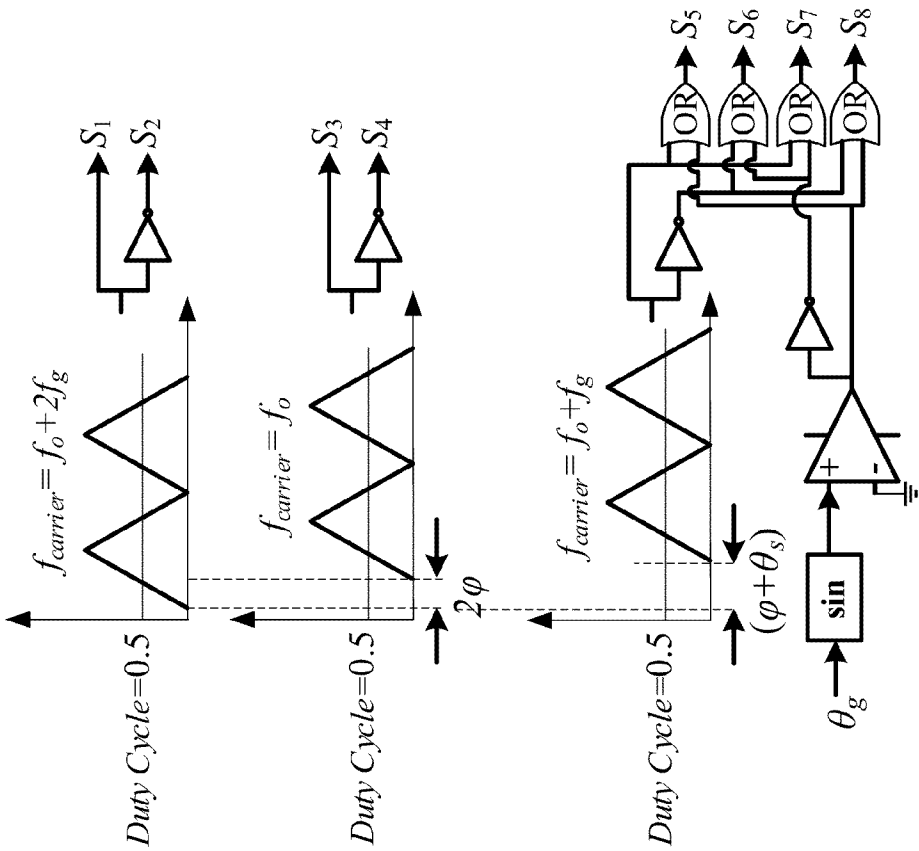
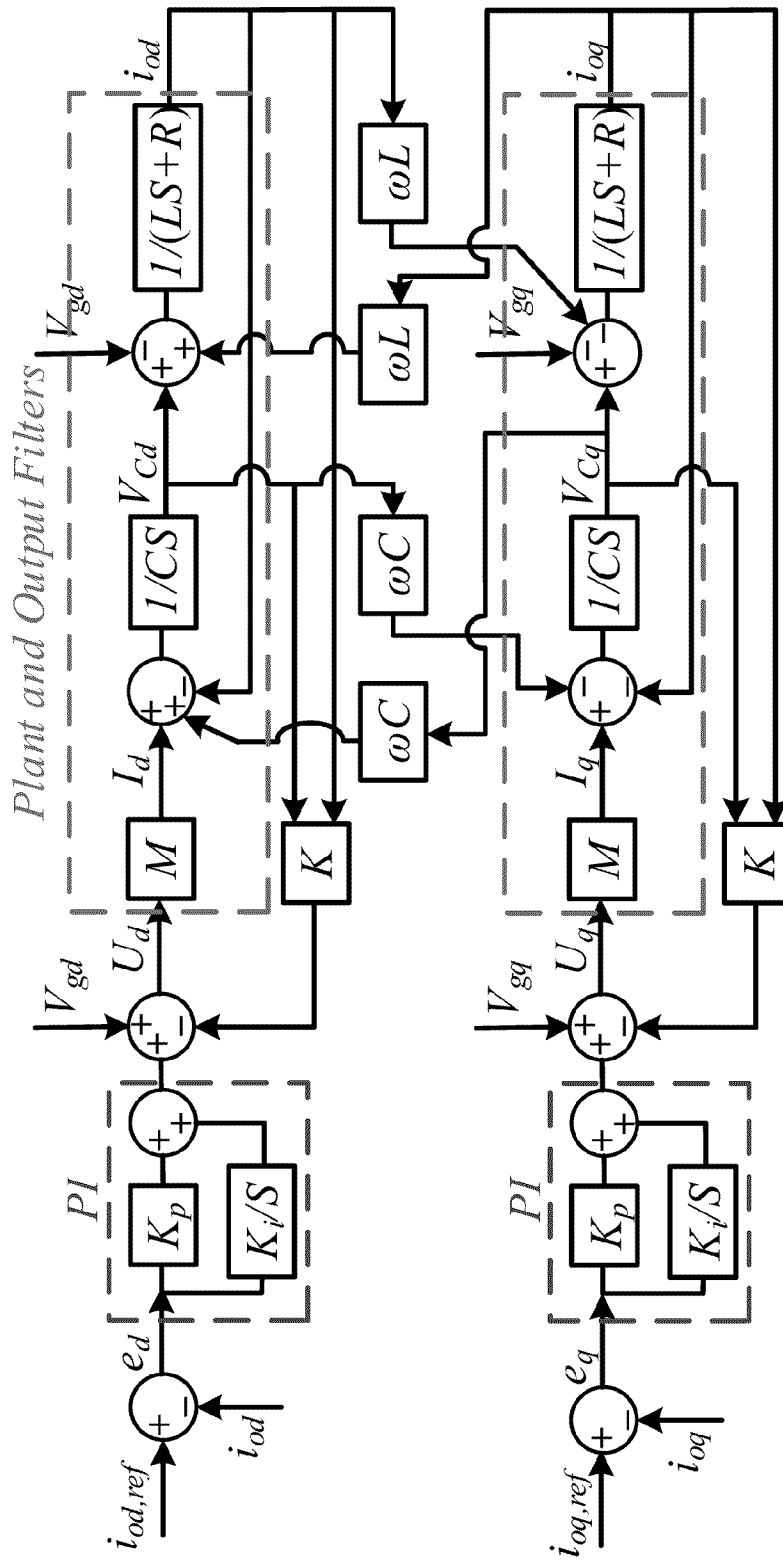


FIG. 12



INTERNATIONAL SEARCH REPORT

International application No.

PCT/CA2024/050323

A. CLASSIFICATION OF SUBJECT MATTER

IPC: **H03B 21/01** (2006.01), **H02M 7/523** (2006.01), **H02S 40/32** (2014.01), **H03C 3/00** (2006.01)CPC: **H03B 21/01** (2020.01), **H02M 7/523** (2020.01), **H02S 40/32** (2020.01), **H03C 3/00** (2020.01)

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)

IPC: *H03B, H02M, H02S, H03C*

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

IPC: *all* CPC: *all*

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

Google; Google Patents; Canadian Patent Database; Questel-Orbit. Terms used: microinverter, photovoltaic, beat, BFM, resonant, LC.

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages			Relevant to claim No.
A	CN116937953A * whole document *	Zhang et al.	24 October 2023 (24-10-2023)	1-14
A	US8861238B2 * whole document *	Huang et al.	14 October 2014 (14-10-2014)	1-14
A	US9048744B2 * whole document *	Fornage et al.	02 June 2015 (02-06-2015)	1-4
A	US9584044B2 * whole document *	Zhou et al.	28 February 2017 (28-02-2017)	1-14

☒ Further documents are listed in the continuation of Box C.☒ See patent family annex.

* "A" "D" "E" "L" "O" "P"	Special categories of cited documents: document defining the general state of the art which is not considered to be of particular relevance document cited by the applicant in the international application earlier application or patent but published on or after the international filing date document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) document referring to an oral disclosure, use, exhibition or other means document published prior to the international filing date but later than the priority date claimed	"T" "X" "Y" "&"	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art document member of the same patent family
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Date of the actual completion of the international search
28 May 2024 (28-05-2024)Date of mailing of the international search report
31 May 2024 (31-05-2024)Name and mailing address of the ISA/CA
Canadian Intellectual Property Office
Place du Portage I, C114 - 1st Floor, Box PCT
50 Victoria Street
Gatineau, Quebec K1A 0C9
Facsimile No.: 819-953-2476

Authorized officer

Andrew O'Malley (819) 635-4706

INTERNATIONAL SEARCH REPORT

International application No.

PCT/CA2024/050323

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US9960712B2 Rodriguez 01 May 2018 (01-05-2018) * whole document *	1-14

INTERNATIONAL SEARCH REPORT

International application No.

PCT/CA2024/050323**Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of the first sheet)**

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claim Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:
2. ☐ Claim Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:
3. ☐ Claim Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

Group I – claim 1 – directed to a beat frequency modulation (BFM) system with two or more converters/switches operated at different frequencies to create an envelope having a lower frequency signal, with rectification to ensure a low frequency sinusoidal waveform.

Group II – claims 2-14 – directed to a microinverter in a photovoltaic system, having first and second resonant LC tank circuits, switching means to combine the first and second resonant frequencies using beat frequency modulation, including a magnetizing inductance (i.e. transformer).

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☒ As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claim Nos.:
4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claim Nos.:

Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.
- ☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.
- ☐ No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/CA2024/050323

Patent Document Cited in Search Report	Publication Date	Patent Family Member(s)	Publication Date
CN116937953A	24 October 2023 (24-10-2023)	CN116937953A CN116937953B	24 October 2023 (24-10-2023) 15 December 2023 (15-12-2023)
US8861238B2	14 October 2014 (14-10-2014)	US2013051102A1 US8861238B2	28 February 2013 (28-02-2013) 14 October 2014 (14-10-2014)
US9048744B2	02 June 2015 (02-06-2015)	US2012170324A1 US9048744B2 CA2823713A1 CN103283133A CN103283133B EP2661804A1 EP2661804A4 EP2661804B1 WO2012094268A1	05 July 2012 (05-07-2012) 02 June 2015 (02-06-2015) 12 July 2012 (12-07-2012) 04 September 2013 (04-09-2013) 13 January 2016 (13-01-2016) 13 November 2013 (13-11-2013) 29 November 2017 (29-11-2017) 01 May 2019 (01-05-2019) 12 July 2012 (12-07-2012)
US9584044B2	28 February 2017 (28-02-2017)	US2014268908A1 US9584044B2	18 September 2014 (18-09-2014) 28 February 2017 (28-02-2017)
US9960712B2	01 May 2018 (01-05-2018)	US2016285387A1 US9960712B2 AU2016235070A1 AU2016235071A1 DE112016001372T5 DE112016001372T8 DE112016001392T5 JP2018509869A JP2018514170A JP6637507B2 US2018241322A1 US10530276B2 US2016285390A1 US9825556B2 WO2016154443A1 WO2016154444A1	29 September 2016 (29-09-2016) 01 May 2018 (01-05-2018) 20 July 2017 (20-07-2017) 20 July 2017 (20-07-2017) 30 November 2017 (30-11-2017) 11 January 2018 (11-01-2018) 14 December 2017 (14-12-2017) 05 April 2018 (05-04-2018) 31 May 2018 (31-05-2018) 29 January 2020 (29-01-2020) 23 August 2018 (23-08-2018) 07 January 2020 (07-01-2020) 29 September 2016 (29-09-2016) 21 November 2017 (21-11-2017) 29 September 2016 (29-09-2016) 29 September 2016 (29-09-2016)

INTERNATIONAL SEARCH REPORT

International application No.

PCT/CA2024/050323

IPC: all

CPC: all