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(71) Applicant *(for all designated States except US)*: BATTERY-BIZ INC. [US/US]; 1380 Flynn Road, Camarillo, California 93012-8016 (US).

(72) Inventor; and
(75) Inventor/Applicant *(for US only)*: MARTEN, Victor [US/US]; 169-15 35th Ave., Flushing, New York 11358 (US).

(74) Agent: OPPEDAHL, Carl; Oppedahl Patent Law Firm LLC, PO Box 4850, Frisco, co 80443-4850 (US).

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(54) Title: HIGH-EFFICIENCY SWITCHED-MODE POWER SUPPLY WITH ASSURED HIGH-FREQUENCY OPERATIONS AT LOW-POWER OUTPUT

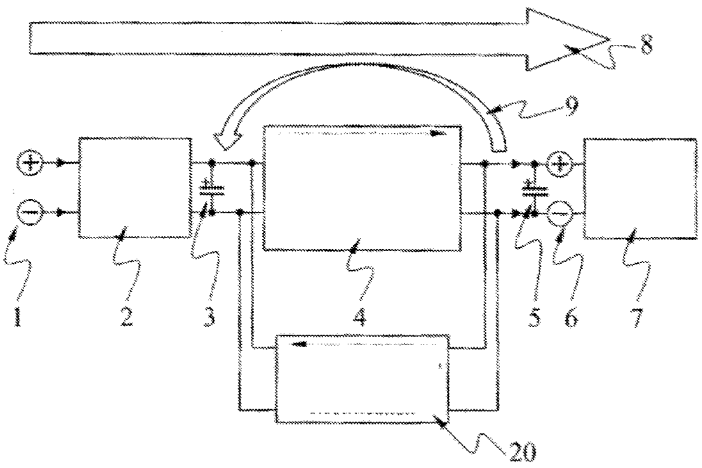

Figure 1

(57) Abstract: The SMPS operates at a reasonably high and inaudible frequency, while enjoying the same high efficiency as the 'Burst Mode' and 'Cycle-Skipping Mode' operations. A reverse-energy flow is introduced into the SMPS, which is used to shorten the time between successive forward-energy-transfer pulses, thereby raising the operating frequency to any desired value. In other words, what is proposed is to remove a small amount of energy from the output-reservoir capacitor and deposit this energy back at the input-reservoir capacitor. Since the transfer of energy via switching-mode converters is nearly lossless, this small amount of energy is simply recycled, moving from the output-reservoir capacitor to the input-reservoir capacitor, and vice-versa. As a result of the proper timing of the reverse-energy-transfer pulses to the input-reservoir capacitor, the proper average output voltage to the load is maintained, while the frequency of the output voltage waveform is increased above the audible range.

WO 2009/145804 A1

High-Efficiency Switched-Mode Power Supply With Assured High-Frequency Operations at Low-Power Output

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims priority from U.S. application number 61/056,911, filed May 29, 2008, which application is incorporated herein by reference for all purposes.

BACKGROUND OF THE INVENTION

The preferred power-conversion method for modern electronic equipment is the Switching-Mode Power Supply (SMPS). It is characterized by high efficiency and resulting low wasted heat dissipation. However, operations of SMPS over the entire load range from zero to full power are problematic.

Energy transfer in the SMPS is related to the timing (duration and repetition rate or frequency) of the internally generated pulses. The condition of low-output power is achieved by shortening the pulses and slowing the repetition rate (decreasing the frequency) of these power-transfer pulses. Practical limits for the minimum duration of the power-transfer pulses necessitate significant decrease of the operating frequency, often in the sub-10 kHz range. Industry terms for this mode of operations are “Burst Mode” and “Cycle-Skipping Mode”, signifying the fact that some (often, most) of the power-transfer pulses are simply suppressed, which amounts to reduction of the average operating frequency.

However, it is highly undesirable to operate at a low frequency, as the magnetostrictive effects, and other effects, in the components of the SMPS manifest themselves as audible noise, which is annoying and disturbing to humans and pets. Therefore, it is desirable to have the operating frequency of the SMPS to be above the highest audible frequency, or over 25-30 kHz.

As a simple solution to the audible noise, many SMPS designs simply utilize a constant minimal “dummy” load at the output. It is clear to anyone practicing the art that efficiency of this solution is very poor under the condition of low power consumed by the actual load.

BRIEF SUMMARY OF THE INVENTION

The proposed invention allows an SMPS to operate at a reasonably high and inaudible frequency, while enjoying the same high efficiency as the “Burst Mode” and “Cycle-

Skipping Mode" operations. The actual, minimal operating frequency can be readily adjusted without a prohibitive penalty to system efficiency.

The invention introduces a reverse-energy flow into the SMPS, which is used to shorten the time between successive forward-energy-transfer pulses, thereby raising the operating frequency to any desired value. In other words, what is proposed is to remove a small amount of energy from the output-reservoir capacitor and deposit this energy back at the input-reservoir capacitor. Since the transfer of energy via switching-mode converters is nearly lossless, this small amount of energy is simply recycled, moving from the output-reservoir capacitor to the input-reservoir capacitor, and vice-versa in a "ping-pong" fashion.

This reverse transfer of energy could be carried out in the SMPS with an Auxiliary Reverse Switching, Magnetics, and Rectification Module or directly by the Main Reverse Switching, Magnetics, and Rectification Module itself. If an Auxiliary Reverse Switching, Magnetics, and Rectification Module is used, it may be possible to carry-out the reverse energy flow simply by a slight adjustment of the timing of the control pulses (if the Main Reverse Switching, Magnetics, and Rectification Module utilizes so-called "synchronous rectifiers"), or by the addition of a switching element on the output side of the Main Reverse Switching, Magnetics, and Rectification Module. This additional switching element can be much smaller (and thus cheaper) than the regular switching elements in the Main Reverse Switching, Magnetics, and Rectification Module because the amount of energy the additional switching element has to control is much smaller as compared to the overall output of the SMPS.

As a result of the proper timing of the reverse-energy-transfer pulses to the input-reservoir capacitor, the proper average output voltage to the load is maintained, while the frequency of the output voltage waveform is increased above the audible range.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 depicts one embodiment of conceptual SMPS with assured high-frequency operations at low power.

Figure 2 depicts a typical prior-art SMPS output voltage profile.

Figure 3a depicts one embodiment of SMPS output voltage profiles for the current invention.

Figure 3b depicts one embodiment of SMPS output voltage profiles for the current invention.

DETAILED DESCRIPTION

First Embodiment — An SMPS With Reverse-Energy Transfer

An exemplary SMPS is shown in Figure 1, which depicts one embodiment of a conceptual SMPS with assured high-frequency operations at low power. Terminals (1) accept direct-current (DC) input. This input energy can come from a variety of sources, such as a battery, as DC distribution bus generated by another SMPS, or an AC/DC rectification circuit (possibly with Power Factor Corrections) drawing energy from an ordinary wall outlet. An Electro-Magnetic Interference (EMI) filter (2) provides attenuation of switching noise and prevents said noise from being injected back into the power source. This filter works in conjunction with the input capacitor (3), which stores the energy temporarily and provides smoothed voltage to the Main Switching, Magnetics, and Rectification Module (4). This module transforms an input voltage level into another output voltage level. The output-reservoir capacitor (5) provides smoothing of the output voltage level, temporarily storing the output energy before it is transferred and consumed by the load (7) by way of output terminals (6).

Figure 1 depicts an arrow (8) showing the direction of the energy flow. Since the whole purpose of the SMPS is to transform the voltage at the input to another voltage at the output (with corresponding, but inversely related, transformation of the currents), the normal energy flow is depicted in the direction of arrow (8).

A typical, previous-art SMPS has an output voltage profile as depicted in the exemplary waveform shown in Figure 2. At the condition of zero or low-energy consumption by the load (Figure 1: 7), the output voltage level will have a defined (designed-for) average level, which is depicted by curve (10), an upward transition (11) stemming from the energy transfer (that the SMPS can supply due to the limitations on the minimum duration of the pulses), and a slow output-voltage-decay transition (12) due to the output load current.

A person ordinarily skilled in the art will immediately recognize that under the condition of low-power consumption by the load (Figure 1: 7), the time interval between the minimum energy transfer pulses should necessarily be relatively long in order to help ensure a constant average output voltage.

Refer back to Figure 1. This embodiment of the present invention introduces a reverse-energy flow (9), which is used to shorten the time between successive forward-energy-transfer pulses, thereby raising the operating frequency to any desired value. In other words, what is proposed is to remove a small amount of energy from the output-reservoir capacitor (5) and deposit this energy back at the input-reservoir capacitor (3). Since the transfer of energy via switching-mode converters is nearly lossless, this small amount of energy is simply recycled, moving from the output-reservoir capacitor (5) to the input-reservoir capacitor (3), and vice-versa in a “ping-pong” fashion.

In an alternate embodiment, the reverse transfer of energy (9) could be carried out with an Auxiliary Reverse Switching, Magnetics, and Rectification Module (20) or directly by the Main Reverse Switching, Magnetics, and Rectification Module (4) itself. If an Auxiliary Reverse Switching, Magnetics, and Rectification Module (20) is used, it may be possible to carry-out the reverse energy flow simply by a slight adjustment of the timing of the control pulses (if the Main Reverse Switching, Magnetics, and Rectification Module (4) utilizes so-called “synchronous rectifiers”), or by the addition of a switching element on the output side of the Main Reverse Switching, Magnetics, and Rectification Module (4). This additional switching element can be much smaller (and thus cheaper) than the regular switching elements in the Main Reverse Switching, Magnetics, and Rectification Module (4) because the amount of energy the additional switching element has to control is much smaller as compared to the overall output of the SMPS.

Exemplary output voltage waveforms resulting from SMPS operations using the present embodiment are shown in Figures 3a and 3b. Figure 3a shows the output voltage profile of a method where reverse transfer is delayed (possibly to occur somewhere in the middle between the forward-energy–transfer pulses). This voltage profile is associated with the implementation with a separate Auxiliary Reverse Switching, Magnetics, and Rectification Module (Figure 1: 20). The average output voltage is indicted by curve (10). The forward-energy-transfer pulses result in rising edges (13), the reverse-energy-transfer pulses result in falling edges (15), and the down-slope portions of the curve (14 and 16) are caused by the output-load current.

Alternatively, Figure 3b shows the output voltage waveforms for the case where the reverse-energy transfer is created by an implementation that uses only the Main Reverse Switching, Magnetics, and Rectification Module (Figure 1: 4) by delaying the deactivation of the output synchronous rectifiers. Producing the same average output voltage level (10), the forward-energy-transfer pulses create edges (17), the reverse-energy-transfer pulses results in edges (18), and the load current produces down-sloping portions of the curve (19).

One ordinarily skilled in the art will recognize that many other waveforms could be created, and while being dissimilar, such alternative waveforms will in no way deviate from the idea proposed by this embodiment. Further, a practitioner in the art will also realize that the waveforms depicted in Figures 3a and 3b are preferable over the prior-art waveforms depicted in Figure 2 because the higher-frequency content depicted in Figures 3a and 3b can be more-easily filtered, resulting in a less-noisier output from the SMPS.

Since the operations with small reverse-energy transfer do not substantially affect the overall efficiency of the SMPS, it is possible, for simplification of the control circuit, to continue the reverse-energy transfers even in the case of large output power being consumed by the load. In other words, the parameters of the reverse-energy transfers do not need to be adjusted depending on the power consumed by the load. In most circuit's implementations, it will be sufficient to produce a fixed-duration pulse to an Auxiliary Reverse Switching, Magnetics, and Rectification Module (Figure 1: 20), or to cause a fixed-duration delay in the deactivation of the synchronous rectifiers in the Main Reverse Switching, Magnetics, and Rectification Module (Figure 1: 4).

Second Embodiment — A Power Adapter With Reverse-Energy Transfer

This embodiment is comprised of a power adapter, comprising a first capacitor receiving direct-current power from a first input; a switched-mode power supply receiving direct current at a first voltage from said first capacitor and providing current to a second capacitor, thereby yielding a second voltage at said second capacitor, said second voltage differing from said first voltage; a power output providing power from said second capacitor to a load external to the power adaptor; and a charge-transfer means that transfers charge from said second capacitor to said first capacitor.

This embodiment can be further extended wherein the charge-transfer means is a reverse-energy-flow controller, wherein said reverse-energy-flow controller transfers a portion of the energy from said second capacitor to said first capacitor, wherein said transfer of a portion of the energy from said second capacitor to said first capacitor is fed back through said main switching, magnetics, and rectification module, and wherein said reverse energy shortens the time between successive forward energy transfer pulses, and thereby raises the operating frequency.

This embodiment can be further extended wherein said operating frequency is raised to above the highest audible frequency.

This embodiment can be further extended wherein said highest audible frequency is 30 kHz.

This embodiment can be further extended wherein said reverse-energy-flow controller comprises said main switching, magnetics, and rectification module.

This embodiment can be further extended wherein said main switching, magnetics, and rectification module uses synchronous rectifiers, and wherein the control pulses of said synchronous rectifiers are slightly adjusted such that said operating frequency is raised.

This embodiment can be further extended wherein said main switching, magnetics, and rectification module uses an auxiliary reverse-switching, magnetics, and rectification module.

Third Embodiment — Method of Use With A Power Adapter With Reverse-Energy Transfer

This embodiment employs a method of use with a power adapter, comprising the steps of providing a first capacitor receiving direct-current power from a first input; providing a switched-mode power supply receiving direct current at a first voltage from said first capacitor and providing current to a second capacitor, thereby yielding a second voltage at said second capacitor, said second voltage differing from said first voltage; providing a power output providing power from said second capacitor to a load external to the power adaptor; and providing a charge-transfer means that transfers charge from said second capacitor to said first capacitor.

This embodiment can be further extended wherein the charge-transfer means is a reverse-energy-flow controller, wherein said reverse-energy-flow controller transfers a portion of the energy from said second capacitor to said first capacitor, wherein said transfer of a portion of the energy from said second capacitor to said first capacitor is fed back through said main switching, magnetics, and rectification module, and wherein said reverse energy shortens the time between successive forward energy transfer pulses, and thereby raises the operating frequency.

This embodiment can be further extended wherein said operating frequency is raised to above the highest audible frequency.

This embodiment can be further extended wherein said highest audible frequency is 30 kHz.

This embodiment can be further extended wherein said reverse-energy-flow controller comprises said main switching, magnetics, and rectification module.

This embodiment can be further extended wherein said main switching, magnetics, and rectification module uses synchronous rectifiers, and wherein the control pulses of said synchronous rectifiers are slightly adjusted such that said operating frequency.

This embodiment can be further extended wherein said main switching, magnetics, and rectification module uses an auxiliary reverse-switching, magnetics, and rectification module.

Fourth Embodiment — Method of Transferring Portion of SMPS Output Charge to SMPS Input

This embodiment employs a method for use with a system having a first capacitor receiving direct-current power from a first input; a switched-mode power supply receiving direct current at a first voltage from said first capacitor and providing current to a second capacitor, thereby yielding a second voltage at said second capacitor, said second voltage differing from said first voltage; a power output providing power from said second capacitor to a load external to the power adaptor; and a charge-transfer means that transfers charge from said second capacitor to said first capacitor; the method comprising the step of transferring charge from said second capacitor to said first capacitor.

Potential Obvious Variations and Improvements

Those skilled in the art will have no difficultly devising myriad obvious variations and improvements to the invention, all of which are intended to be encompassed within the scope of the claims which follow.

CLAIMS

What is claimed is:

1. A power adapter, comprising:

a first capacitor receiving direct-current power from a first input;

a switched-mode power supply receiving direct current at a first voltage from said first capacitor and providing current to a second capacitor, thereby yielding a second voltage at said second capacitor, said second voltage differing from said first voltage;

a power output providing power from said second capacitor to a load external to the power adaptor; and

a charge-transfer means that transfers charge from said second capacitor to said first capacitor.

2. The power adapter of claim 1, wherein the charge-transfer means is a reverse-energy-flow controller,

wherein said reverse-energy-flow controller transfers a portion of the energy from said second capacitor to said first capacitor,

wherein said transfer of a portion of the energy from said second capacitor to said first capacitor is fed back through said main switching, magnetics, and rectification module, and

wherein said reverse energy shortens the time between successive forward energy transfer pulses, raising operating frequency.

3. The power adapter of claim 2, wherein said operating frequency is raised to above the highest audible frequency.

4. The power adapter of claim 3, wherein said highest audible frequency is 30 kHz.

5. The power adapter of claim 2, wherein said reverse-energy-flow controller comprises said main switching, magnetics, and rectification module.

6. The power adapter of claim 5, wherein said main switching, magnetics, and rectification module uses synchronous rectifiers, and

wherein the control pulses of said synchronous rectifiers are slightly adjusted such that said operating frequency is raised.

7. The power adapter of claim 5, wherein said main switching, magnetics, and rectification module uses an auxiliary reverse-switching, magnetics, and rectification module.

8. A method for use with a power adapter, comprising the steps of:

providing a first capacitor receiving direct-current power from a first input;

providing a switched-mode power supply receiving direct current at a first voltage from said first capacitor and providing current to a second capacitor, thereby yielding a second voltage at said second capacitor, said second voltage differing from said first voltage;

providing a power output providing power from said second capacitor to a load external to the power adaptor; and

providing a charge-transfer means that transfers charge from said second capacitor to said first capacitor.

9. The method of claim 8, wherein the charge-transfer means is a reverse-energy-flow controller,

wherein said reverse-energy-flow controller transfers a portion of the energy from said second capacitor to said first capacitor,

wherein said transfer of a portion of the energy from said second capacitor to said first capacitor is fed back through said main switching, magnetics, and rectification module, and

wherein said reverse energy shortens the time between successive forward energy transfer pulses, raising operating frequency.

10. The method of claim 9, wherein said operating frequency is raised to above the highest audible frequency.

11. The method of claim 10, wherein said highest audible frequency is 30 kHz.

12. The method of claim 9, wherein said reverse-energy-flow controller comprises said main switching, magnetics, and rectification module.

13. The method of claim 12, wherein said main switching, magnetics, and rectification module uses synchronous rectifiers, and

wherein the control pulses of said synchronous rectifiers are slightly adjusted such that said operating frequency is raised.

14. The method of claim 12, wherein said main switching, magnetics, and rectification module uses an auxiliary reverse-switching, magnetics, and rectification module.

15. A method for use with a system having a first capacitor receiving direct-current power from a first input; a switched-mode power supply receiving direct current at a first voltage from said first capacitor and providing current to a second capacitor, thereby yielding a second voltage at said second capacitor, said second voltage differing from said first voltage; a power output providing power from said second capacitor to a load external to the power adaptor; and a charge-transfer means that transfers charge from said second capacitor to said first capacitor; the method comprising the step of:

transferring charge from said second capacitor to said first capacitor.

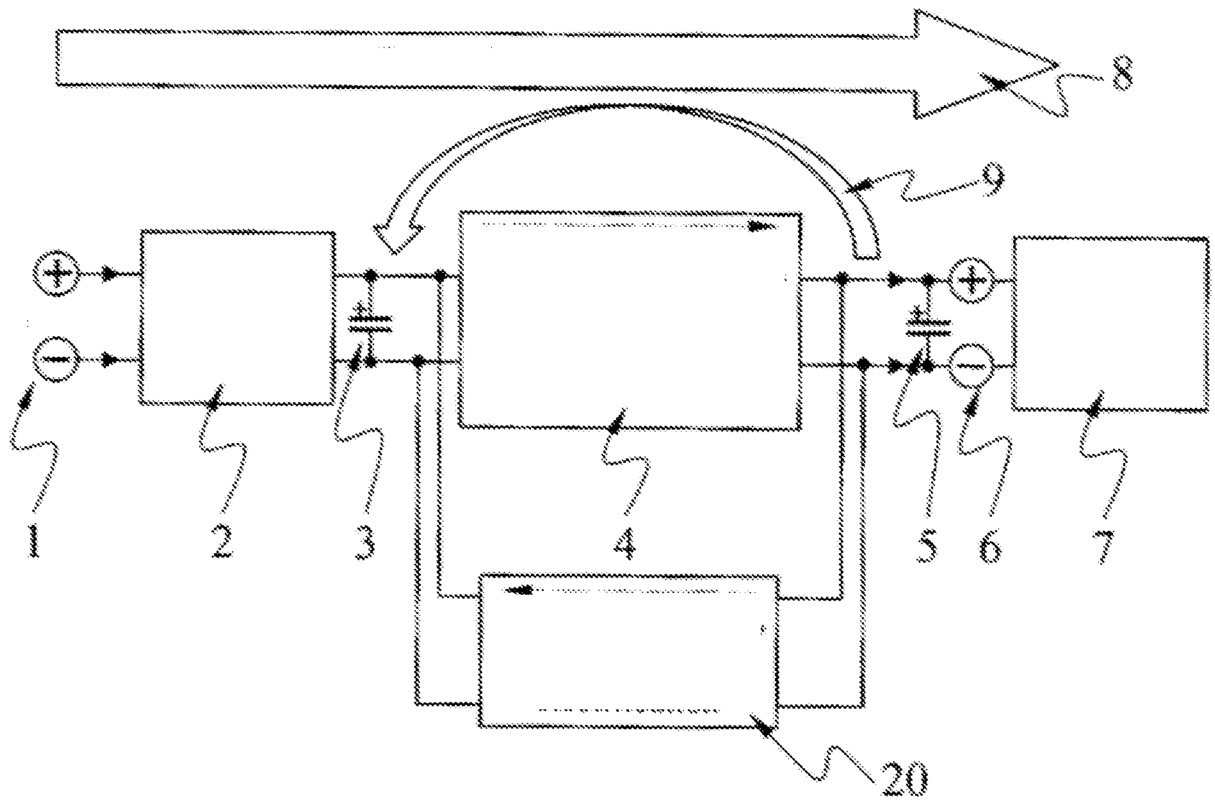

Figure 1

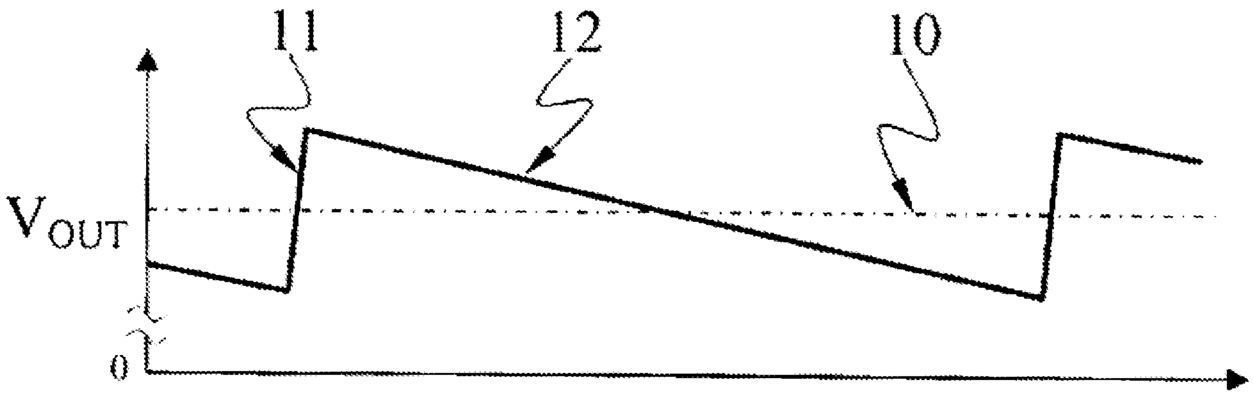

Figure 2

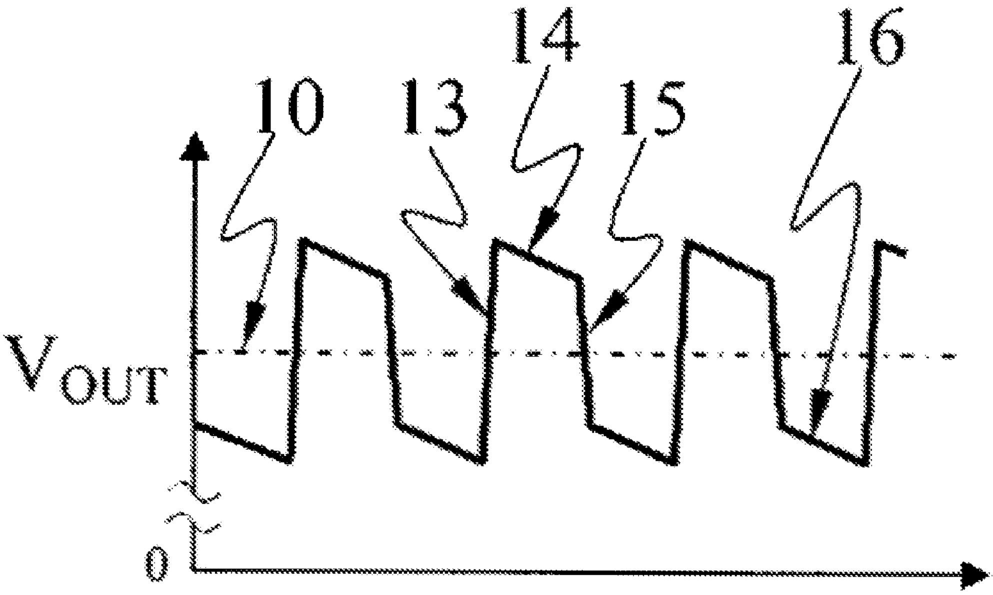

Figure 3a

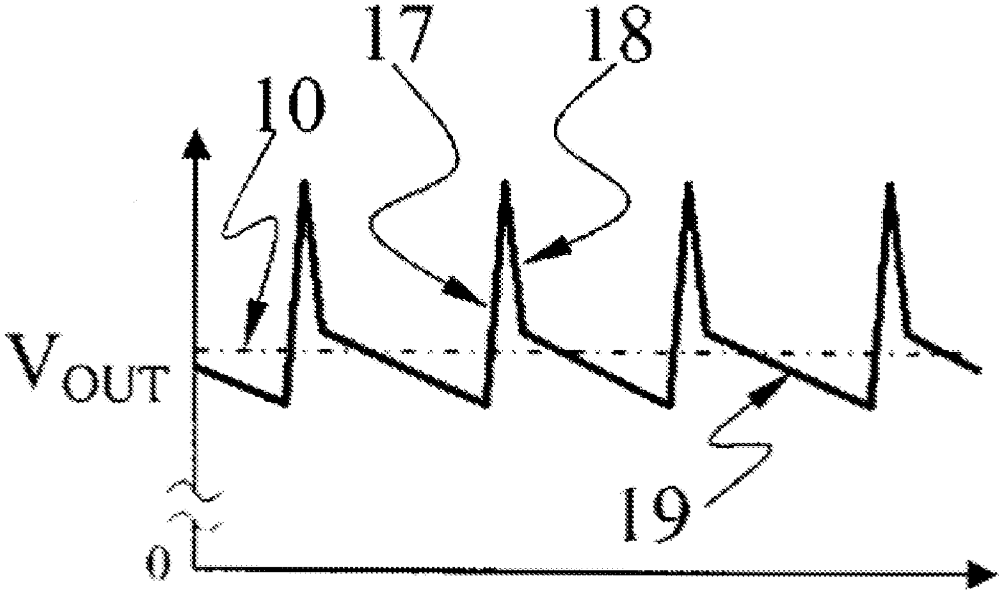

Figure 3b

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2008/082948

A. CLASSIFICATION OF SUBJECT MATTER

H02M 3/28(2006.01)i, H02M 3/155(2006.01)i

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 B60H 1/32, H02J 1/00, H02M 3/28, H02M 3/155, H02M 7/48, H05B 41/282

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Korean Utility models and applications for Utility models since 1975
Japanese Utility models and applications for Utility models since 1975

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
e-KIPASS(KIPO internal) "bidirectional", "converter", "dc to dc", "feedback", "recovery ", "frequency", "synchronous rectifier"

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	JP 04-372578 A (Seiko Epson Corp) 25 Dec. 1992 see the abstract, claim 1, paragraph [0005]-[0021], figures 1-2	1-15
A	JP 2000-152619 A (NEC Corp) 30 May 2000 see the abstract, claims 1-10, figures 1-6	1-15
A	JP 2006-288103 A (Nippon Soken Inc, Denso Corp) 19 Oct. 2006 see the abstract, claims 1-12, figures 1-22	1-15
A	Leon M. Tolbert et. al., "A Bi-Directional DC-DC Converter with Minimum Energy Storage Elements" 2002 IEEE Industry Applications Conference, Vol. 3, Oct. 2002.	1-15

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

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" 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
"X" 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
"Y" 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

Date of the actual completion of the international search	Date of mailing of the international search report
17 JUNE 2009 (17.06.2009)	**17 JUNE 2009 (17.06.2009)**

Name and mailing address of the ISA/KR
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Government Complex-Daejeon, 139 Seonsa-ro, Seo-gu, Daejeon 302-701, Republic of Korea
Facsimile No. 82-42-472-7140

Authorized officer
BAE, Jin Yong
Telephone No. 82-42-481-8503

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	Fang Z. Peng et. al. "A New ZVS Bidirectional DC-DC Converter for Fuel Cell and Battery Application" 2004 IEEE Transactions on Power Electrons, Vol. 19, No. 1, Jan. 2004.	1-15
A	H. Tap et. al. "Multi-Input Bidirectional DC-DC Converter Combining DC-Link and Magnetic-Coupling for Fuel Cell Systems" 2005 IEEE Industry Applications Conference, Vol. 3, Oct. 2005.	1-15

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2008/082948

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		US 7269035 B2	11.09.2007