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(71) Applicant: MEGGER SWEDEN AB [SE/SE]; Box 724,
182 17 DANDERYD (SE).

(72) Inventor: STANISIC, Zoran; Hembergavägen 23, 187 73
TÄBY (SE).

(74) Agent: BERGENSTRÄHLE & PARTNERS STOCK-
HOLM AB; Box 17704, 118 93 Stockholm (SE).

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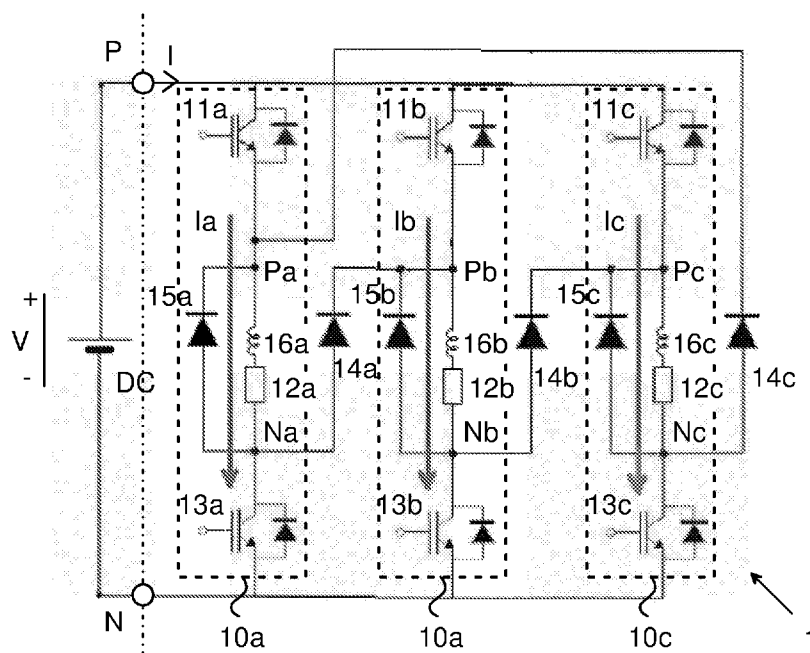


Fig. 1a

(57) Abstract: A device is connectable to a DC voltage source for loading the DC voltage source. The device comprises a plurality of legs (10a, 10b, 10c) connected in parallel between a first terminal and a second terminal, wherein each leg comprises, a first semiconductor switch element (11a, 11b, 11c), a second semiconductor switch element (13a, 13b, 13c), a resistive element (12a, 12b, 12c) connected and a rectifier element (14a, 14b, 14c) having an anode and a cathode. The cathode of each of the rectifier elements is connected to a first node of a subsequent leg, wherein the cathode of a last leg is connected to the first node of the first leg. A device for loading a voltage source wherein the load current is controlled is thereby provided. A corresponding method is also disclosed.

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UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ,
TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK,
EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV,
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DEVICE AND METHOD FOR LOADING A VOLTAGE SOURCE

Technical field

[0001] The present invention relates generally to loading of voltage sources and more particularly to a device and a method for loading a voltage source wherein the load current is controlled.

Background art

[0002] Batteries are used to ensure that critical electrical equipment is always on. There are many places where batteries are used and some of the applications for batteries include electric generating stations and substations for protection and control of switches and relays, telephone systems to support phone service, industrial applications for protection and control and back up of computers.

[0003] There are some main reasons to test battery systems: to insure the supported equipment is adequately backed-up, to prevent unexpected failures by tracking the battery's health, and to forewarn/predict permanent failure there are three basic questions that battery users ask: What is the capacity and the condition of the battery now? When will it need to be replaced? What can be done to improve / not reduce its life?

[0004] Batteries are complex chemical mechanisms. They have numerous components from grids, active material, posts, jar and cover, etc. – any one of which can fail. As with all manufacturing processes, no matter how well they are made, there is still some amount of uncertainty related to batteries.

[0005] A battery is two dissimilar metallic materials in an electrolyte. Nonetheless, to work the way it is supposed to work a battery must be maintained properly. A good battery maintenance program may prevent, or at least, reduce the costs and damage to critical equipment due to an AC mains outage, for example.

[0006] Batteries come in various configurations themselves. Add to that the many ways that they can be arranged and it is realized that the number of

possible configurations is endless. Voltage plays the biggest part in a battery configuration. Batteries have multiple posts for higher current draws. The more current needed from a battery, the bigger the connections must be. That includes posts, intercell connectors and bus bars and cables. The many configurations of batteries mean that testing equipment must be adaptable to different voltages and currents etc.

[0007] There are a number of standards and company practices for battery testing. Usually they comprise inspections (observations, actions and measurements done under normal float condition) and capacity tests. Most well-known are the IEEE standards: IEEE 450 for flooded lead-acid, IEEE 1188 for sealed lead-acid, and IEEE 1106 for nickel-cadmium.

[0008] So-called capacity tests or discharge tests are performed at the time of installation of batteries and then periodically, depending on the capacity of the battery. Capacity test is the only way to get an accurate value on the actual capacity of the battery. While used regularly it can be used for tracking the battery's health and actual capacity and estimating remaining life of the battery. When the battery is new its capacity might be slightly lower than specified. This is normal.

[0009] During the test it is measured how much capacity (current times time expressed in Ah) the battery can deliver before the terminal voltage drops to the end of discharge voltage times number of cells. During testing, the current shall be maintained at a constant value. It is recommended to select a test time that is approximately the same as the battery's duty cycle.

[0010] Batteries can also be tested at a shorter time than their duty cycle, for instance at 1 hour. Then the current rate has to be increased. An advantage is that less capacity is drained from the battery (valid for lead-acid) and it requires less time to recharge it. Also less man-hour is needed for the test.

[0011] Tests are thus usually conducted at constant current, but constant power, constant resistance or a pre-selected load profile can also be used. This implies that the discharge current must be controlled in a flexible and still reliable way.

Summary of the invention

[0012] An object of the present invention is therefore to provide a device and a method for loading a voltage source wherein the load current is controlled.

[0013] According to a first aspect of the invention there is provided a device connectable to a DC voltage source for loading the DC voltage source, the DC voltage source having a positive terminal and a negative terminal, the device comprising: a first terminal connectable to the positive terminal of the DC voltage source, a second terminal connectable to the negative terminal of the DC voltage source, a plurality of legs comprising a first leg, a second leg and further legs until a last leg, wherein the plurality of legs are connected in parallel between the first terminal and the second terminal, wherein each leg comprises, a first semiconductor switch element having a first end and a second end, wherein the first end of the first semiconductor switch element is connected to the first terminal, a second semiconductor switch element having a first end and a second end, wherein the second end of the second semiconductor switch element is connected to the second terminal, a resistive element connected, at a first node, to the second end of the first semiconductor switch element, and a second node, to the first end of the second semiconductor switch element, and a rectifier element having an anode and a cathode, wherein the anode of the rectifier element is connected to the second node, wherein the cathode of each of the rectifier elements is connected to the first node of a subsequent leg, wherein the cathode of a last leg is connected to the first node of the first leg.

[0014] In a preferred embodiment, the number of legs is three.

[0015] In a preferred embodiment, the number of legs is eight.

[0016] In a preferred embodiment, each of the semiconductor switch elements comprises a transistor with an anti-parallel diode.

[0017] In a preferred embodiment, each of the resistive elements comprises a resistor connected in series with a parasite inductor.

[0018] According to a second aspect of the invention there is provided a method for loading a voltage source by means of the device, the method comprising the following steps: a) determining operating parameters for discharging the DC voltage source, b) measuring the voltage of the DC voltage source, c) determining a control scheme based on the operating parameters and the measured voltage of the DC voltage source, d) measuring physical entities, e) adjusting the control scheme based on the measured physical entities, and repeating steps d) and e) until an end condition is fulfilled.

[0019] In a preferred embodiment, wherein the operating parameters are chosen from the following: voltage, discharge current, discharge time.

[0020] In a preferred embodiment, an effective current in each leg is controlled by adjusting the duty cycle of the semiconductor switch elements.

[0021] In a preferred embodiment, an effective current is conducted in two or more legs at a time, with a cyclical commutation between the different legs.

[0022] In a preferred embodiment, a switching frequency per leg is less than 20 kHz.

Brief description of drawings

[0023] The invention is now described, by way of example, with reference to the accompanying drawings, in which:

Fig. 1a is a circuit diagram of a first embodiment of a device according to the invention in a first mode of operation, the device having three legs.

Fig. 1b is the same circuit diagram as in Fig. 1a but showing a second mode of operation,

Fig. 1c is the same circuit diagram as in Fig. 1a but showing a third mode of operation,

Fig. 2a is a curve diagram showing the currents flowing in the device of Figs. 1a-c in the first mode of operation,

Fig. 2b is a curve diagram showing the combined currents flowing in the device of Figs. 1a-c in the first mode of operation,

Figs. 3a-c are diagrams showing different timings of the switches shown in Figs. 1a-c,

Fig 4 is a circuit diagram of a second embodiment of a device according to the invention, having eight legs,

Fig. 5 shows an example of serially connecting two devices according to the invention, and

Fig. 6 shows a device adapted to provide a variable voltage output.

Description of embodiments

[0024] In the following, a detailed description of a device and a method according to the invention will now be given.

[0025] Referring first to Fig. 1a, the layout of a device for loading a DC voltage source, generally designated 1, is shown. The device is connectable to a DC voltage source, referenced DC, having a positive terminal and a negative terminal. The device has a first terminal P connectable to the positive terminal of the DC voltage source and a second terminal N connectable to the negative terminal of the DC voltage source.

[0026] A plurality of legs 10a, 10b, 10c, in the embodiment shown in Figs. 1a-c three legs, enclosed by dashed lines, are connected in parallel between the first terminal P and the second terminal N. Each leg comprises a first switch element 11a, 11b, and 11c, respectively, having a first end and a second end, wherein the first end of the first switch element is connected to the first terminal P. Each leg also comprises a second switch element 13a, 13b, and 13c, respectively, having a

first end and a second end, wherein the second end of the second switch element is connected to the second terminal P.

[0027] In each leg a resistive element 12a, 12b, and 12c, respectively, is connected, at a first node Pa, Pb, and Pc, respectively, to the second end of the first switch element, and a second node Na, Nb, and Nc, respectively, to the first end of the second switch element. A rectifier element 14a, 14b, 14c having an anode and a cathode, is connected to the respective second node by means of its anode. Also, the cathode of each of the rectifier elements is connected to the first node of a subsequent leg, wherein the cathode of a last leg is connected to the first node of the first leg. Thus, in this case the rectifier element 14c is connected between the third and the first legs.

[0028] Each of the switch elements 11a-c and 13a-c comprises in the preferred embodiment a semiconductor switch, such as a transistor with an anti-parallel diode. Each switch element is controlled by control electronics (not shown in the figures).

[0029] Each of the resistive elements 12a, 12b, and 12c comprises in the preferred embodiment a resistor connected in series with a parasite inductor 16a, 16b and 16c. This results in a time constant for the current changes. Also, it is preferred to provide flywheel diodes 15a, 15b and 15c for handling reverse currents.

[0030] The device 1 operates as follows. First, it is connected by means of the terminals P, N to a battery source DC to be tested, i.e., to be discharged in a controlled way. Different parameters are entered into the control electronics, such as voltage, discharge current, discharge time etc. Based on these parameters, an operating mode is selected to obtain the best possible discharge scheme.

[0031] According to Ohm's law, the discharge current is determined by the voltage V across the DC voltage source and the resistance of the resistive elements 12a, 12b, 12c. The effective resistance of these resistive elements will be determined by the operation mode, as will be described in the following.

[0032] The resistive elements can be connected in different configurations depending on the state of the different switches 11a-c and 13a-c, i.e. if they are ON (closed, conducting current) or OFF (open, interrupting current). This means that the resistive elements can be connected in parallel, in series, or a combination of in parallel and in series.

[0033] In Fig. 1a an operation mode is shown wherein all switches are on, conducting current through each leg 10a-c from the positive terminal P to the negative terminal N, shown by arrows in the figure. This means that the three resistive elements 12a-c are connected in parallel. Assuming that each resistive element has the resistance value R, the resulting current I will be the following:

$$I=3V/R$$

[0034] In Fig 1b an operation mode is shown wherein the switches 11a, 13b, 11c, and 13c are ON and the remaining switches 13a and 11b are OFF. In this mode, the current is conducted from the positive terminal, through the first resistive element 12a, via the rectifying element 14a, and through the second resistive element 12b to the negative terminal N. In other words, the first and second resistive elements 12a, 12b are connected in series. The third resistive element 12c in the third leg 10c conducts current from the positive terminal P to the negative terminal N. Thus, two resistive elements connected in series are connected in parallel with one single resistive element. Assuming that each resistive element has the resistance value R, the resulting current I will be the following:

$$I=3V/2R$$

[0035] In Fig 1c an operation mode is shown wherein the switches 11a and 13c are ON and the remaining switches 13a, 11b, 13b, and 11c are OFF. In this mode, the current is conducted from the positive terminal, through the first resistive element 12a, via the first rectifying element 14a, through the second resistive element 12b, via the second rectifying element 14b, and via the third resistive element 13c to the negative terminal N. In other words, the first, second, and third

resistive elements 12a, 12b, 12c are connected in series. Assuming that each resistive element has the resistance value R , the resulting current I will be the following:

$$I = V/3R$$

[0036] The total current I loading the voltage source is the sum of the currents in the three legs 10a-c, i.e., $I_a + I_b + I_c$. By switching the different switches in an intelligent way, the total current I can be controlled to a desired value which is shown on Fig. 3a. The effective current in each leg can also be controlled by adjusting the duty cycle of the switches. Referring again to Fig. 1a, instead of conducting current in all three legs simultaneously, current can be conducted first in the first leg 10a, then in the second leg 10b, then in the third leg 10c, then again in the first leg 10a and so on. Alternatively, the effective current can be conducted in two or more legs at a time, with a cyclical commutation between the different legs. For example, current can be conducted first in the first and second legs 10a, 10b, then in the second and third legs 10b, 10c, then in the third and first legs 10c, 10a, then again in the first and second legs 10a, 10b and so on. In this cyclic switching way, all semiconductor switches are equally used, dissipating same power, no matter of chosen topology, which results in uniform heat spreading and reduced heat needed to be dissipated from each of the components included in the device.

[0037] In more general terms, if the maximum total current, in when current flows in all three legs, is designated I_{Max} , and the duty cycle is designated $D=(0..1)$, then the current I loading the voltage source is

$$I = D \times I_{Max}$$

[0038] An example of the currents is illustrated in Figs. 2a and 2b. Referring to the examples described with reference to Fig. 1a, Fig. 2a show the different currents I_a , I_b , and I_c , conducted through the first, second, and third leg 10a, 10b, 10c, respectively. In Fig. 2b, the total current $I = I_a + I_b + I_c$ is shown by a thick line. By switching the switches with a high enough frequency, i.e., commuting the

current between the different legs with high frequency, the current ripple can be kept low enough to satisfy the requirements of the discharge operation, i.e., with an essentially constant current I . For example, as switching frequency of 20 kHz per leg will be sufficient, resulting in 60kHz of total current ripple and minimizing filter components needed for filtering the same.

[0039] Different cyclic switching schemes are illustrated in Figs. 3a-c. Transistor steering in Fig. 3a is used for highest discharging current, resulting in highest frequency of current ripple. For medium discharging current, transistors can be operated as on Fig. 3b and for lowest discharging current and highest battery voltage, transistor switches are operated as on Fig. 3c. According to maximum current ripple frequency, adequate current filter can be dimensioned and implemented, such as filter 17 in Fig. 4.

[0040] A method of loading a DC voltage source by means of a device according to the invention will now be described. Initially, operating parameters such as discharge duration, for example 1 h, discharge current etc. are determined. These parameters are input into the control electronics controlling the operation of the switches of the device. The voltage of the voltage source is then measured by means of a voltage meter. This voltage meter can be a separate measuring device but is preferably integrated in the device 1 for loading the voltage source.

[0041] A control scheme is then determined based on the measured voltage and the operating parameters. Switching of the switches according to the control scheme is then initiated. Different physical entities, such as the voltage V across the voltage source, the total current I , the current in the different legs, the temperature at different locations, such as the switches and the resistive elements, etc. are continuously monitored and the control scheme is adjusted in dependence of the values of the different physical entities. For example, when the voltage V across the voltage source decreases over time as it is discharged, in order to maintain a constant current I , the effective resistance of the resistive elements must be decreased. This can be effected by adjusting the duty cycle of the

different switches and/or changing the operation mode. For example, instead of an operation mode wherein the different resistive elements are connected in series between the positive terminal P and the negative terminal N, resulting in an effective resistance $3 \times R$, they can be connected in parallel, resulting in an effective resistance $R/3$, assuming 100 % duty cycle.

[0042] The physical entities are measured either continuously or with regular intervals and the control scheme is adjusted based on the measured physical entities until an end condition is fulfilled. This can be that a predetermined time has lapsed from the start of the discharge, the voltage of the DC source has dropped below a threshold value, an alarm condition etc.

[0043] An alternative embodiment of the device according to the invention is shown in Fig. 4. The general structure is similar to the one described above with reference to Figs. 1a-c, but in this case the device is provided with eight legs 10a-h instead of three. This number: $2 \times 2 \times 2$, allows a number of suitable switching schemes.

[0044] More than one device can be connected in series or parallel, allowing handling of higher voltages or higher current. One example thereof is shown in Fig. 5, wherein the positive terminal of a master device 1 is connected to the positive pole of the voltage source. The negative pole of the master device is connected to the positive terminal P of a slave device 1'. The negative terminal N of the slave device is connected to the negative pole of the voltage source. In this way, twice the voltage level can be handled as compared to the voltage level handled by a single device, assuming that the master and slave devices have the same voltage ratings.

[0045] It will be appreciated that more than two devices can be connected in series, such as one master device and two slave devices.

[0046] A different application can be obtained by replacing the resistive elements with transformers or DC bridges, allowing power to be input into the device

resulting in a variable DC output voltage between the positive terminal P and the negative terminal N. An example of such an embodiment is shown in Fig. 6.

[0047] Preferred embodiments of a device and a method according to the invention have been described. It will be appreciated that these can be varied within the scope of the appended claims without departing from the inventive idea. For example, the inventive idea is applicable on a device comprising as few as two legs.

CLAIMS

1. A device connectable to a DC voltage source for loading the DC voltage source, the DC voltage source having a positive terminal and a negative terminal, the device comprising:

a first terminal (P) connectable to the positive terminal of the DC voltage source,

a second terminal (N) connectable to the negative terminal of the DC voltage source,

a plurality of legs (10a, 10b, 10c) comprising a first leg (10a), a second leg (10b) and further legs until a last leg, wherein the plurality of legs are connected in parallel between the first terminal and the second terminal, wherein each leg comprises,

a first semiconductor switch element (11a, 11b, 11c) having a first end and a second end, wherein the first end of the first semiconductor switch element is connected to the first terminal (P),

a second semiconductor switch element (13a, 13b, 13c) having a first end and a second end, wherein the second end of the second semiconductor switch element is connected to the second terminal (N),

a resistive element (12a, 12b, 12c) connected, at a first node (Pa, Pb, Pc), to the second end of the first semiconductor switch element, and a second node (Na, Nb, Nc), to the first end of the second semiconductor switch element, and

a rectifier element (14a, 14b, 14c) having an anode and a cathode, wherein the anode of the rectifier element is connected to the second node (Na, Nb, Nc),

wherein the cathode of each of the rectifier elements is connected to the first node of a subsequent leg, wherein the cathode of a last leg is connected to the first node of the first leg.

2. The device according to claim 1, wherein the number of legs (10a, 10b, 10c) is three.

3. The device according to claim 1, wherein the number of legs (10a, 10b, 10c) is eight.

4. The device according to any one of claims 1-3, wherein each of the semiconductor switch elements (11a-c, 13a-c) comprises a transistor with an anti-parallel diode.

5. The device according to any one of claims 1-4, wherein each of the resistive elements (12a-c) comprises a resistor connected in series with a parasite inductor (16a-c).

6. A method for loading a DC voltage source by means of a device according to claim 1, the method comprising the following steps:

- a) determining operating parameters for discharging the DC voltage source (DC),
- b) measuring the voltage of the DC voltage source (DC),
- c) determining a control scheme based on the operating parameters and the measured voltage of the DC voltage source,
- d) measuring physical entities,
- e) adjusting the control scheme based on the measured physical entities, and
- f) repeating steps d) and e) until an end condition is fulfilled.

7. The method according to claim 6, wherein the operating parameters are chosen from the following: voltage, discharge current, discharge time.

8. The method according to claim 6 or 7, wherein an effective current in each leg is controlled by adjusting the duty cycle of the semiconductor switch elements.
9. The method according to any one of claims 6-8, wherein an effective current is conducted in two or more legs at a time, with a cyclical commutation between the different legs.
10. The method according to any one of claims 6-9, wherein a switching frequency per leg is less than 20 kHz.

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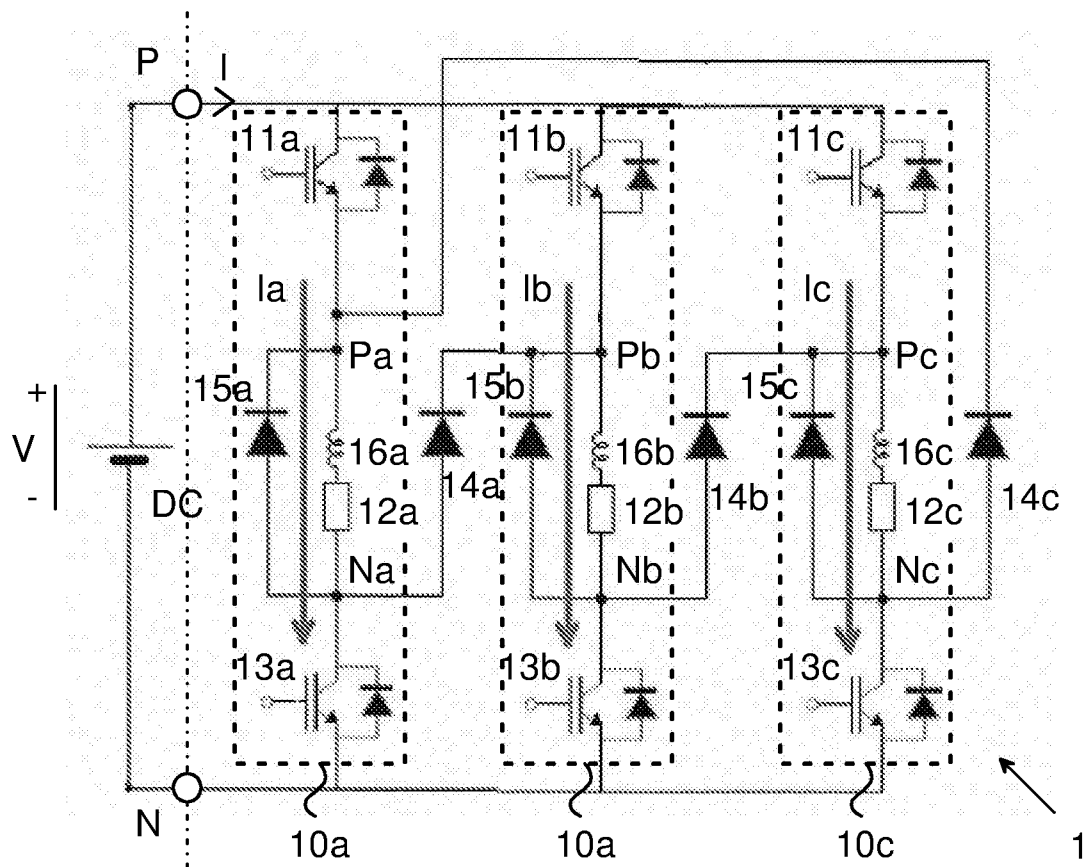


Fig. 1a

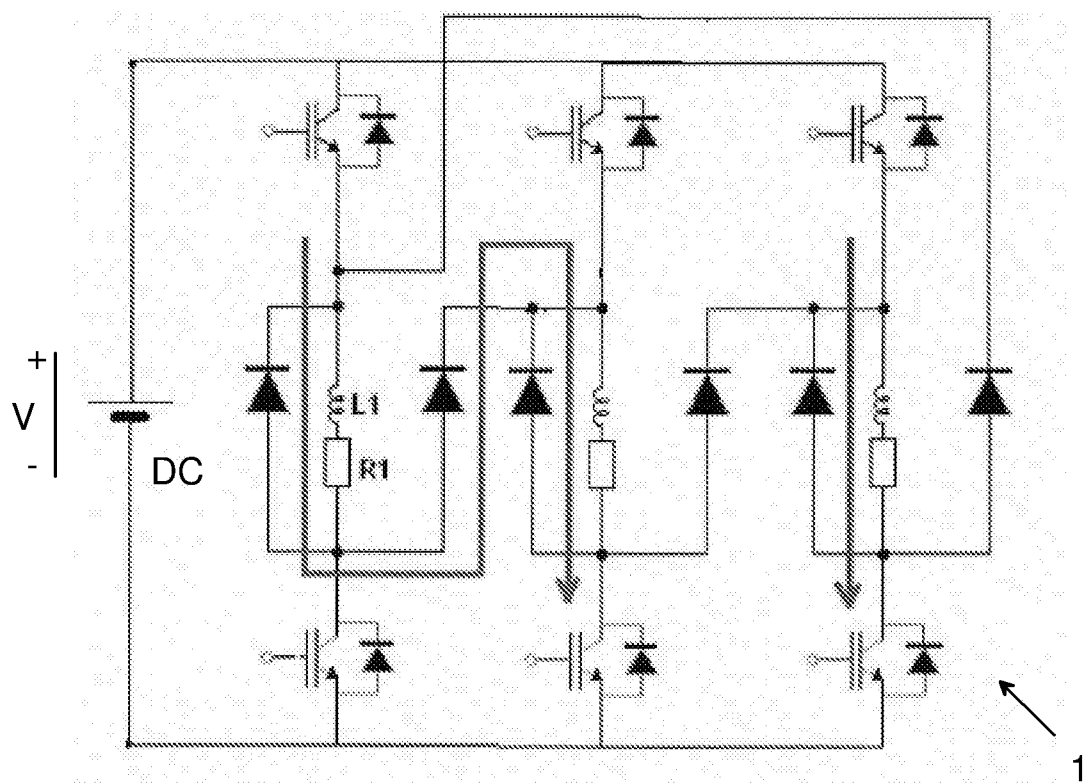


Fig. 1b

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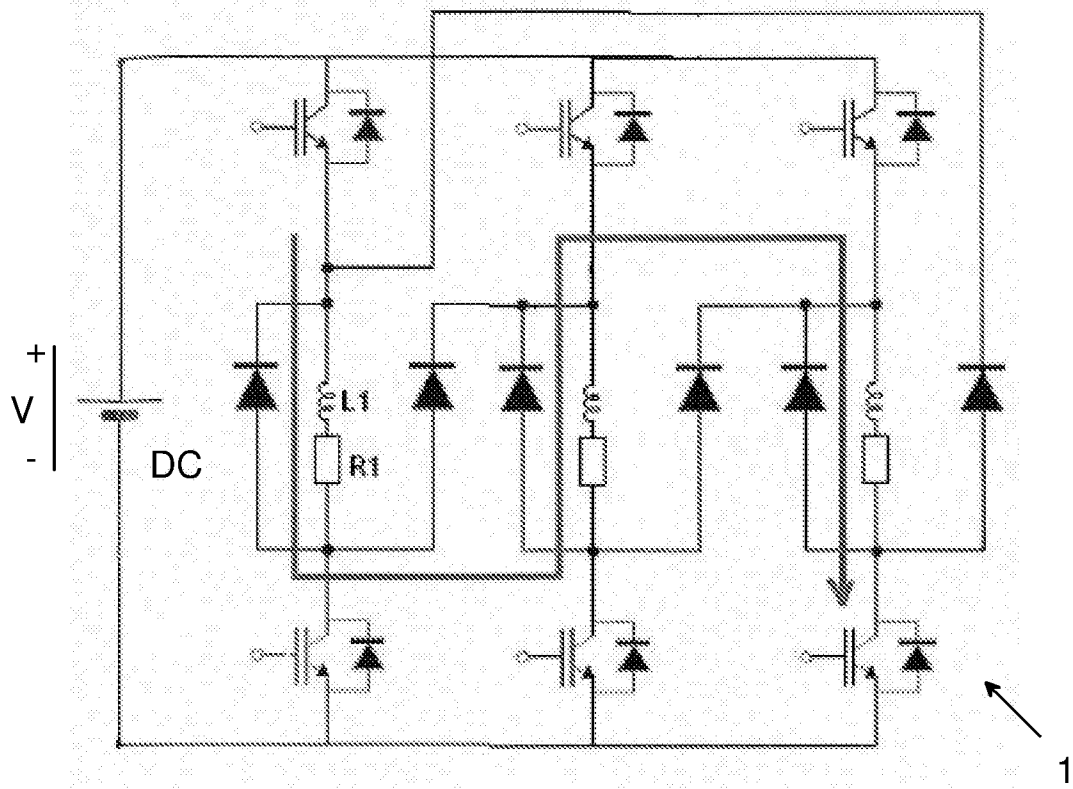


Fig. 1c

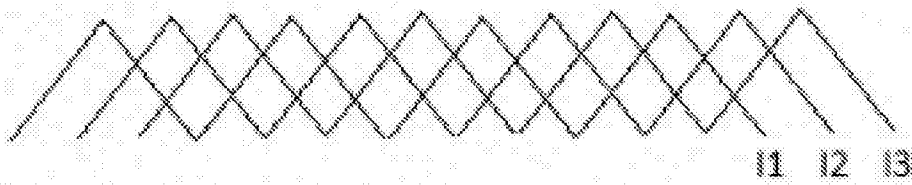


Fig. 2a

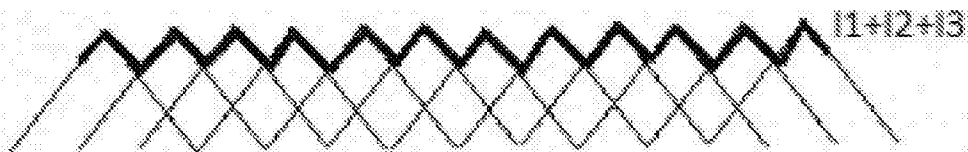


Fig. 2b

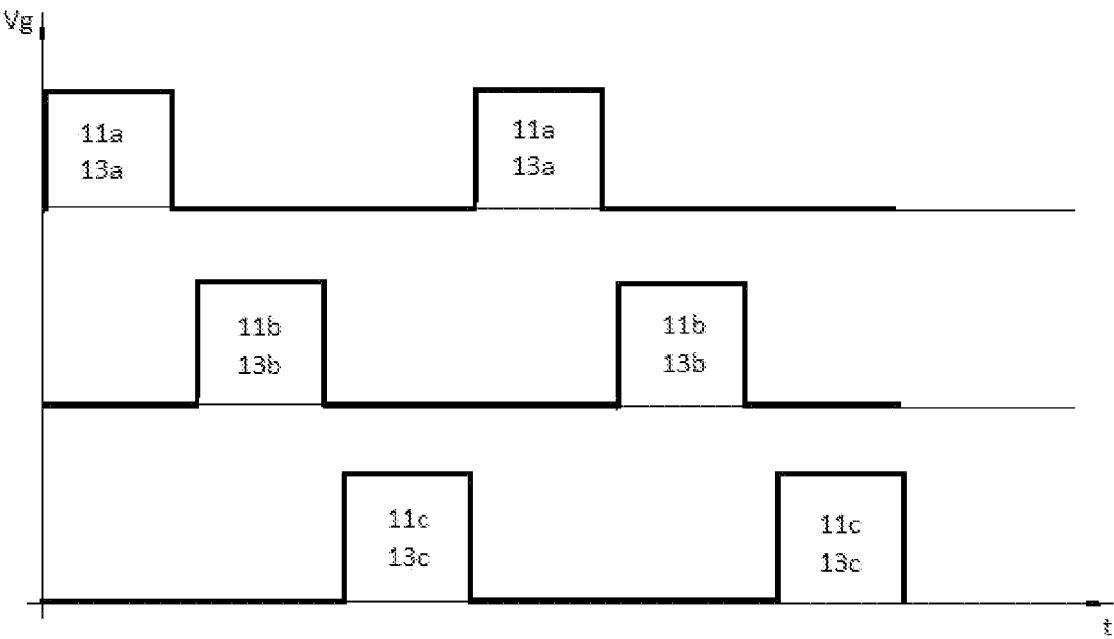


Fig. 3a

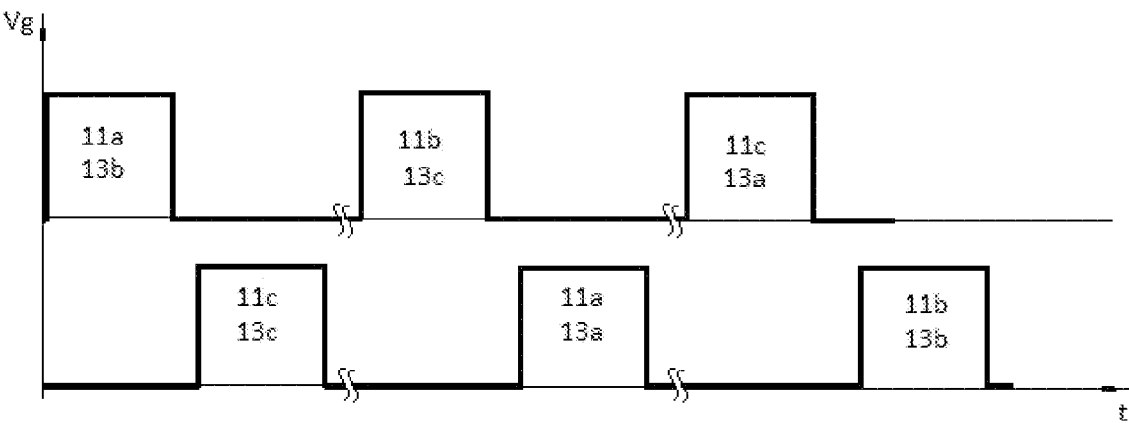


Fig. 3b

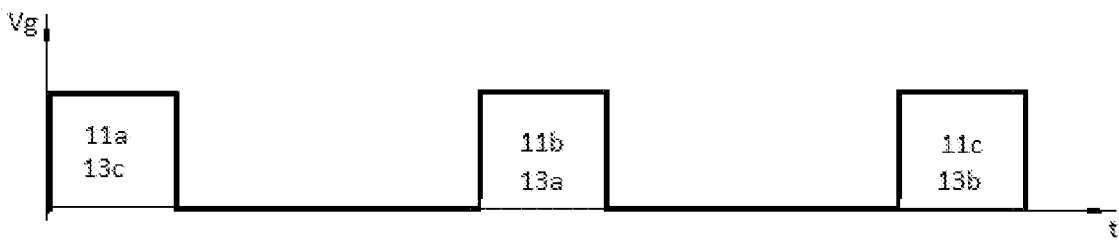


Fig. 3c

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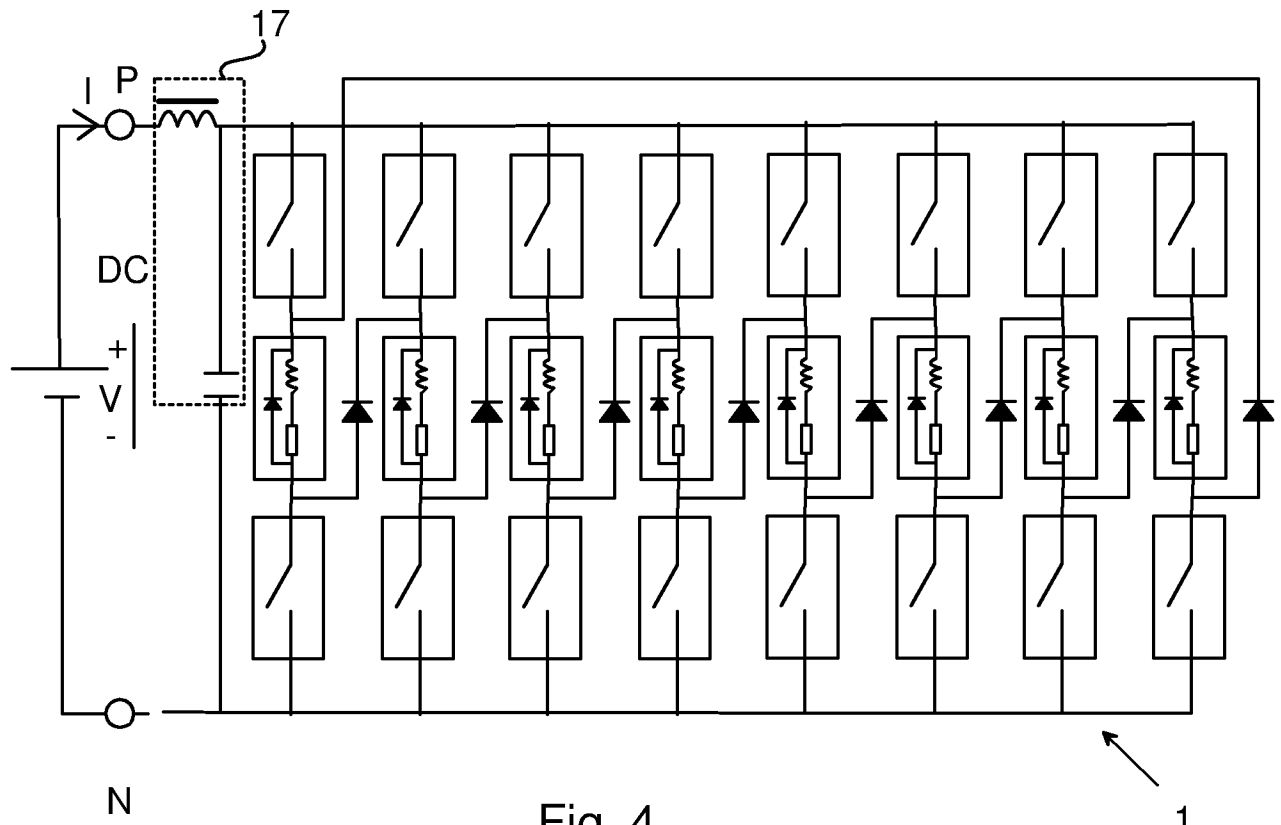


Fig. 4

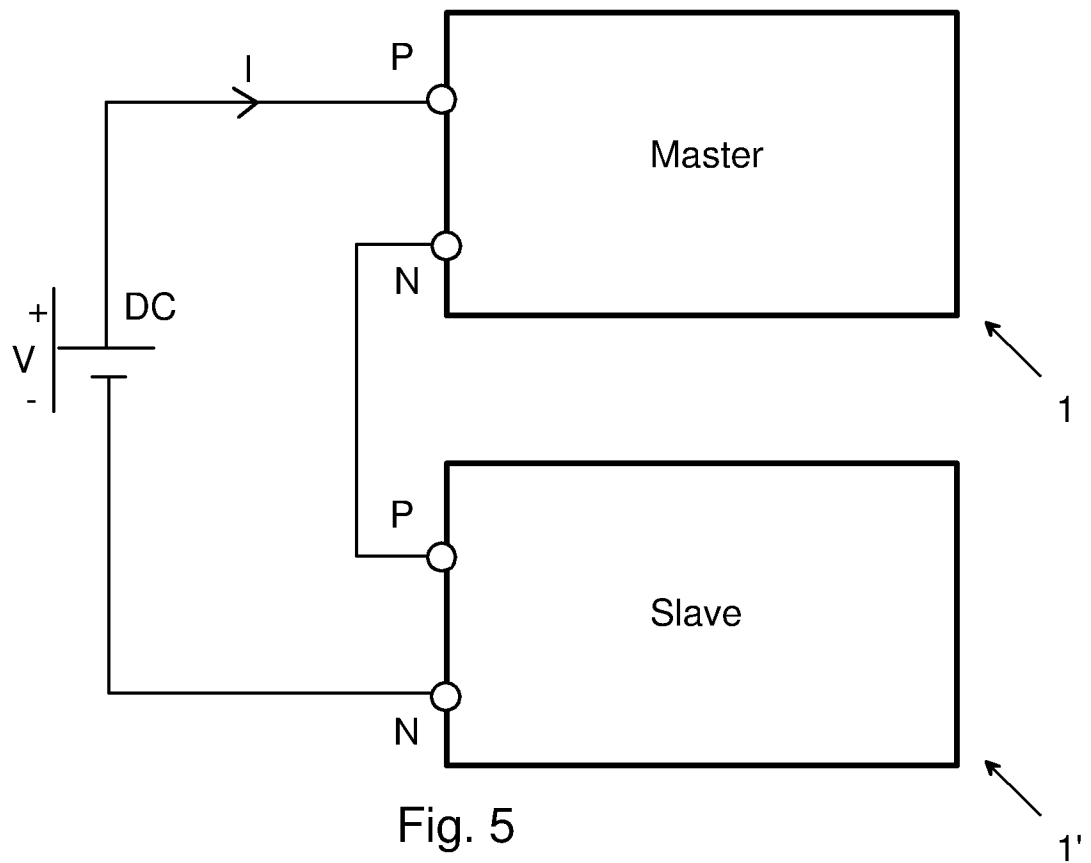


Fig. 5

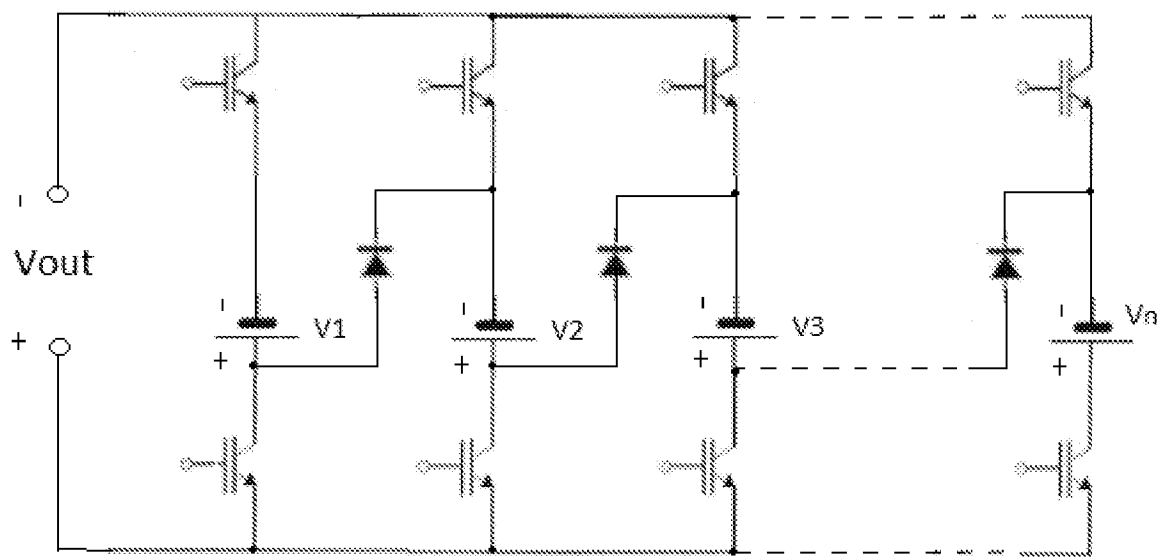


Fig. 6

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE2017/050588

A. CLASSIFICATION OF SUBJECT MATTER

IPC: see extra sheet

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: G01R, H01M, H02J

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

SE, DK, FI, NO classes as above

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

EPO-Internal, PAJ, WPI data, COMPENDEX, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	EP 2838152 A1 (MITSUBISHI ELECTRIC CORP), 18 February 2015 (2015-02-18); abstract; paragraphs [0026]-[0033], [0043]-[0045], [0063]-[0065], [0075]-[0076], [0083]-[0084]; figures --	1-10
A	US 20150355281 A1 (LEE IN HEE ET AL), 10 December 2015 (2015-12-10); paragraphs [0021]-[0024], [0057]-[0062]; figure 6 --	1-10
A	WO 9901918 A2 (ESTCO ENERGY INC ET AL), 14 January 1999 (1999-01-14); page 1, line 1 - line 8; page 7, line 14 - page 8, line 12; figure 1; claim 4 --	1-10



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents:	"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
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Date of the actual completion of the international search

31-08-2017

Date of mailing of the international search report

01-09-2017

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Facsimile No. + 46 8 666 02 86

Authorized officer

Jenny Wallner

Telephone No. + 46 8 782 28 00

INTERNATIONAL SEARCH REPORT

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C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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