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(54) Title: DC SYSTEM AND ITS CONTROL METHOD

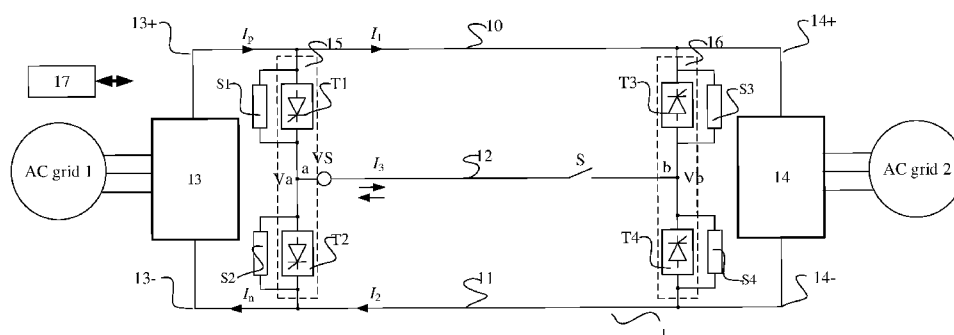


Figure 1

(57) **Abstract:** It provides a DC system converted from an AC system with phase line A, phase line B and phase line C and its control method. The DC system includes: a first converter station and a second converter station connected by a first phase line and a second phase line selected from the phase line A, the phase line B and the phase line C for transmission of DC power therebetween; a first leg being arranged to connect across DC side of the first converter station, having a first controllable power switch in its upper leg and a second controllable power switch in its lower leg, which are connected in series via a first middle point; a second leg being arranged to connect across DC side of the second converter station, having a third controllable power switch in its upper leg and a fourth controllable power switch in its lower leg, which are connected in series via a second middle point; a bi-directional power switch, being arranged in a third phase line selected from the phase line A, the phase line B and the phase line C; and a controller; wherein: the third phase line is arranged to connect the first middle point and the second middle point; and the controller is configured to turn on the bi-directional power switch and both of the controllable power switches in the respective upper/lower legs so as to allow a current to flow through them. By having the above solutions, at different stages, the controller controls to either turn on the bi-directional power switch and the power switches in the upper portion of the legs; or turn on the bi-directional power switch and the power switches in the lower portion of the legs. In the former situation, the full current between the two stations is carried by the second phase line, whereas the first phase line and the third phase line are sharing the current flowing in the other direction; and in the latter situation, the full current between the two stations is carried by the first phase line, whereas the second phase line and the third phase line are sharing the current flowing in the other direction.

SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN,
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DC SYSTEM AND ITS CONTROL METHOD

Technical Field

- 5 This invention relates generally to a DC system, and more particularly to a mid-voltage DC system upgraded from an AC system, such like an AC distribution network.

Background Art

10 Tri-pole converter solution is normally used as a result of conversion of selected existing AC lines in an AC system to DC lines in a DC system. A tri-pole solution for AC to DC line conversion is disclosed in Aziz Aghazadeh, Conversion HVAC into HVDC of Power transmission lines with using voltage source converter, 29th International Power System Conference - 2014 Tehran, Iran. In the tri-pole solution, all the three conductors in one line will be fully used to have the maximum boosting of power transmission capacity.

15 Distributed capacitors of pole 2 line are charged during its operation in either of the two modes: mode I: both of the pole 1 and pole 2 lines conduct current in the same direction and pole 3 line in the reverse; and mode II: both of the pole 2 and the pole 3 conduct current in the same direction and pole 1 line in the reverse. For example, in mode I, the distributed capacitors of the pole 2 line are charged and thus its level of potential is
20 maintained above the ground level. When commuting from mode I to mode II, a combination of the discharging current from the distributed capacitors to negative pole will flow through power switches cause an overcurrent in them. Similar procedure will also happen during the transient from mode II to mode I. The overcurrent caused by the discharging of line capacitors is not desirable because it may damage the power electronics
25 devices.

To resolve this issue, paper, F. Xu. Research on Key Technologies of AC-to-DC Transmission Lines Conversion. PhD thesis. Zhejiang University, 2015: p48-49, teaches to insert a current regulation converter (CRC) and current limiting resistors on the pole 2 line to limit the discharging current. However, the additional converters increase the system
30 cost and control complexity.

Brief Summary of the Invention

According an aspect of present invention, it provides a DC system converted from an AC system with phase line A, phase line B and phase line C, including: a first converter station and a second converter station connected by a first phase line and a second phase line
5 selected from the phase line A, the phase line B and the phase line C for transmission of DC power therebetween; a first leg being arranged to connect across DC side of the first converter station, having a first controllable power switch in its upper leg and a second controllable power switch in its lower leg, which are connected in series via a first middle point; a second leg being arranged to connect across DC side of the second converter
10 station, having a third controllable power switch in its upper leg and a fourth controllable power switch in its lower leg, which are connected in series via a second middle point; a bi-directional power switch, being arranged in a third phase line selected from the phase line A, the phase line B and the phase line C; and a controller; wherein: the third phase line is arranged to connect the first middle point and the second middle point; and the controller
15 is configured to turn on the bi-directional power switch and both of the controllable power switches in the respective upper/lower legs so as to allow a current to flow through them.

According to another aspect of present invention, it provides a method for controlling a DC system converted from an AC system with phase line A, phase line B and phase line C, wherein: the DC system includes: a first converter station and a second converter station
20 connected by a first phase line and a second phase line selected from the phase line A, the phase line B and the phase line C; a first leg being arranged to connect across DC side of the first converter station, having a first controllable power switch in its upper leg and a second controllable power switch in its lower leg, which are connected in series via a first middle point; a second leg being arranged to connect across DC side of the second
25 converter station, having a third controllable power switch in its upper leg and a fourth controllable power switch in its lower leg, which are connected in series via a second middle point; a bi-directional power switch, being arranged in a third phase line selected from the phase line A, the phase line B and the phase line C; and the third phase line is arranged to connect the first middle point and the second middle point; the method
30 includes: turn on the bi-directional power switch and both of the controllable power switches in the respective upper/lower legs so as to allow a current to flow through them.

By having the above solutions, at different stages, the controller controls to either turn on the bi-directional power switch and the power switches in the upper portion of the legs; or

turn on the bi-directional power switch and the power switches in the lower portion of the legs. In the former situation, the full current between the two stations is carried by the second phase line, whereas the first phase line and the third phase line are sharing the current flowing in the other direction; and in the latter situation, the full current between
5 the two stations is carried by the first phase line, whereas the second phase line and the third phase line are sharing the current flowing in the other direction.

Preferably, at least one snubber respectively is connected in parallel with at least one of the first, second, third and fourth controllable power switches. The distributed capacitors of the third phase line will be discharged via the snubber circuits to approximately ground level.
10 Therefore, overcurrent caused by the discharging of distributed capacitors of third phase line will be reduced greatly.

Preferably, a voltage sensor is configured to measure voltage level at the third phase line, and the controller is further configured to turn on both of the bi-directional power switch and one of the both of the controllable power switches in the respective upper/lower legs,
15 and in response to that the measurement of the voltage level reaches a predetermined value turn on the other controllable power switch. By using the solution according to present invention, a bidirectional switch is used instead of a converter. The voltage of the third phase line will be monitored by voltage sensor during the transition. The voltage on third phase line will decrease from the positive voltage level to approximately ground level
20 gradually

Preferably, the voltage sensor is arranged in the first converter station or the second converter station. During the whole operation period, the telecommunication for voltage measurement signal between two converter stations isn't required during normal operation, since the turn-on condition are judged from local measurement by using voltage sensor
25 within the first/second converter station under the assumption that the power flow is from the first power converter station to the second converter station or vice versa.

Brief Description of the Drawings

The subject matter of the invention will be explained in more detail in the following text
30 with reference to preferred exemplary embodiments which are illustrated in the drawings, in which:

Figure 1 schematically illustrates a DC system according to a first embodiment of the invention;

Figures 2A to 2F illustrate operation procedure of the DC system according to figure 1; and

5 Figure 3 illustrates a second embodiment of the invention.

The reference symbols used in the drawings, and their meanings, are listed in summary form in the list of reference symbols. In principle, identical parts are provided with the same reference symbols in the figures.

10

Preferred Embodiments of the Invention

In the following description, for purposes of explanation and not limitation, specific details are set forth, such as particular circuits, circuit components, interfaces, techniques, etc. in order to provide a thorough understanding of the present invention. However, it will be
15 apparent to one skilled in the art that the present invention may be practiced in other embodiments that depart from these specific details. In other instances, detailed descriptions of well-known methods and programming procedures, devices, and circuits are omitted so not to obscure the description of the present invention with unnecessary detail.

20 While the invention is susceptible to various modifications and alternative forms, specific embodiments thereof are shown by way of example in the drawings and will herein be described in detail. It should be understood, however, that the drawings and detailed description thereto are not intended to limit the invention to the particular form disclosed, but on the contrary, the intention is to cover all modifications, equivalents, and alternatives
25 falling within the spirit and scope of the present invention as defined by the appended claims. Note, the headings are for organizational purposes only and are not meant to be used to limit or interpret the description or claims. Furthermore, note that the word "may" is used throughout this application in a permissive sense (i.e., having the potential to, being able to), not a mandatory sense (i.e., must)." The term "include", and derivations thereof,
30 mean "including, but not limited to". The term "connected" means "directly or indirectly connected", and the term "coupled" means "directly or indirectly connected".

Figure 1 schematically illustrates a DC system according to a first embodiment of the

invention, which has been simplified for only showing the components necessary for explaining the invention. This DC system 1 is converted from an AC system by re-using its phase line A, phase line B, and phase line C. A first phase line 10, a second phase line 11 and a third phase line 12 are selected from the phase line A, the phase line B, and the phase line C. For example, the phase line A is selected as the first phase line, the phase line B is selected as the second phase line, and the phase line C is selected as the third phase line.

This DC system 1 comprises at respective ends of the first phase line 10, the second phase line 11 and the third phase line 12, a first converter station 13 and a second converter station 14 for conversion of an alternating voltage into a direct voltage for transmitting direct current between said stations 13, 14 in all three phase lines 10, 11, 12.

Each the converter station 13, 14 comprises a Voltage Source Converter (VSC) having its DC side connected by the first phase line 10 and the second phase line 11. The AC side of the converter station 13, 14 is connected to a three-phase alternating voltage network, generator, load or the like. Each said converter station 13, 14 based VSC has valves of fully controllable power semiconductor devices, such as IGBT, and rectifying members, such as rectifying diodes, in anti-parallel therewith connected in series. As an alternative, each the converter station 13, 14 comprises a Line Commutated Converter (LCC), which has valves of partially controlled power semiconductor devices, such as thyristor, and rectifying members, such as rectifying diodes, in anti-parallel therewith connected in series.

Although for the sake of simplicity only shown for one of the stations 13, 14 each converter station 13, 14 also comprises a control unit for switching the valves by controlling the semiconductor devices thereof for converting said alternating voltage into direct voltage applied to the first phase line 10 and the second phase line 11. The control unit will control the valve according to a Pulse Width Modulation pattern by such switching with a frequency in the range of 50Hz - 10 kHz, through which the power flow direction between the two stations 13, 14 may be controlled, i.e. which one of the stations functions as rectifier and which one as inverter. It is pointed out that a plurality of semiconductor devices and rectifying members may be connected in series in each valve for being able to together hold the voltage to be held by the valve in the blocking stage thereof.

This DC system 1 further includes a first leg 15 and a second leg 16. The first leg 15 is connected across the DC side of the first converter station 13, and it has a first controllable power switch T1 in its upper leg and a second controllable power switch T2 in its lower leg.

The first controllable power switch T1 and the second controllable power switch T2 are connected in series at a first middle point a. In the scenario that either of them is open and the first converter station 13 operates at the sending end (current I_p flows from the positive terminal 13+ of the DC side of the first converter station 13, and current I_n flows into the negative terminal 13- of the DC side of the first converter station 13), anode of the first controllable power switch T1 is connected to the positive terminal 13+ of the DC side of the first converter station 13, and cathode of the second controllable power switch T2 is connected to the negative terminal 13- thereof. Similarly, the second leg 16 is connected across the DC side of the second converter station 14, and it has a third controllable power switch T3 in its upper leg and a fourth controllable power switch T4 in its lower leg. The third controllable power switch T3 and the fourth controllable power switch T4 are connected in series at a second middle point b. In the scenario that the second converter station 14 operates at the receiving end, anode of the fourth controllable power switch T4 is connected to the negative terminal 14- of the DC side of the second converter station 14 and cathode of the third controllable power switch T3 to the positive terminal 14+ thereof.

The DC system 1 further includes a bi-directional power switch S being inserted in the third phase line 12. The third phase line 12 connects the first middle point a and the second middle point b. Where the bi-directional power switch S is open, the electrical connection between the first middle point a and the second middle point b is open, as well. The bi-directional power switch S can be a hybrid type DC breaker or an IGBT/IGCT based DC breaker consisting of anti-series connected IGBT/IGCT switches.

Preferably, as shown in Fig 1, a first, second, third and fourth snubbers S1, S2, S3, S4 are respectively connected with the first, second, third and fourth controllable power switches T1, T2, T3, T4 in parallel.

Figures 2A to 2F illustrate operation procedure of the DC system according to figure 1. The function of the DC system according to figure 1 is controlled by a controller 17. The operation description is based on the assumption that the power flow is from Station 13 to Station 14.

Figure 2A shows the operation at stage 1 [t_0 , t_1]. At t_0 , S is turned on, T1 and T3 are triggered on. The conductor of Third phase line 12 is parallel connected to First phase line 10 to share the positive pole current I_p . The interval of stage 1 could be in minute level depending on the thermal design of conductor and conductor type.

Figure 2B shows the operation at stage 2 [t_1 , t_2]. At t_1 , S is turned off, the trigger signal of

T1 and T3 are removed. The DC current at Third phase line 12 is decreased gradually to zero at t2.

Figure 2C shows the operation at stage 3 [t2, t3]. At t2, S is turned on, T4 is triggered on. Third phase line 12 is de-energized via snubbers S1, S2, S3, S4. The voltage of line C will decrease because the distributed capacitors will be discharged via the snubbers S1, S2, S3, S4. During stage 3, Station 13 will monitor the voltage of Third phase line 12 terminal at Station 13 (Va) via voltage sensor VS. When Va decreases to zero (or below a preset value close to zero), T2 is triggered on, Stage 3 is finished. During this stage, voltage measurement of Va and the control of T2 is realized within Station 13.

Figure 2D shows the operation at stage 4 [t3, t4]. During this stage, T2 is triggered on. The Third phase line 12 is parallel connected to Second phase line 11 to share the negative pole current In.

Figure 2E shows the operation at stage 5 [t4, t5]. At t4, S is turned off, the trigger signal of T2 and T4 are removed. The DC current at Third phase line 12 is decreased to zero at t5.

Figure 2F shows the operation at stage 6 [t5, t6]. at t5, S is turned on, T3 is triggered. Third phase line 12 is de-energized. The voltage of third phase line 12 will increase because the distributed capacitors will be charged via the snubbers S1, S2, S3, S4. During stage 6, Station 13 will monitor the potential of Third phase line 12 terminal at Station 13 (Va). When Va increases to zero (or above a preset value close to zero), T1 is triggered on, Stage 6 is finished. The operation will run into next period. During this stage, the voltage measure of Va and the control of T1 is realized within Station 13.

In summary, the controller 17 is configured to turn on the bi-directional power switch S and both of the controllable power switches in the respective upper/lower legs so as to allow a current to flow through them. For example, as described above, at different stages, the controller 17 controls to either turn on the bi-directional power switch and the power switches T1, T3 in the upper portion of the legs 15, 16, or turn on the bi-directional power switch and the power switches T2, T4 in the lower portion of the legs 15, 16. In the former situation, the full current between the two stations 13, 14 is carried by the second phase line 11, whereas the first phase line 10 and the third phase line 12 are sharing the current flowing in the other direction; and in the latter situation, the full current between the two stations 13, 14 is carried by the first phase line 10, whereas the second phase line 11 and the third phase line 12 are sharing the current flowing in the other direction.

By using the solution according to present invention, a bidirectional switch S is used

instead of a converter. The voltage of the third phase line will be monitored by voltage sensor VS during the transition. For example, at a stage, the third phase line 12 will be disconnected from its parallel operation with the first phase line 10. The voltage on third phase line 12 will decrease from the positive voltage level to approximately ground level gradually. The distributed capacitors of the third phase line 12 will be discharged via the snubber circuits to approximately ground level. Therefore, overcurrent caused by the discharging of distributed capacitors of third phase line 12 will be reduced greatly. Similarly, at another stage, the third phase line 12 will be disconnected from its parallel operation with the second phase line 11, The distributed capacitors of third phase line 12 will be charged via the snubber circuits to approximately ground level and the charging current to the third phase line 12 will be also reduced.

During the whole operation period, the telecommunication for voltage measurement signal between two converter stations 13, 14 isn't required during normal operation, since the turn-on condition of T1 or T2 are judged from local measurement Va by using voltage sensor VS within the first converter station 13 under the assumption that the power flow is from Station 13 to Station 14.

For some applications, the power flow reverse function of the DC system is needed. If the converter stations 13, 14 are line communicated converter (LCC) or full-bridge based voltage source converter (FB-VSC), the topology shown in figure 1 can easily change its voltage polarity of each converter during reverse power flow operation without hardware charges. However, if the converter stations 13, 14 are of half-bridge-based voltage source converter (HB-VSC), the voltage polarity of the converter cannot be changed but the current direction at first phase line 10 and the third phase line 12 should be changed accordingly. Therefore, for HB-VSC based system, the proposed solution can be modified further with additional antiparallel thyristors (or bidirectional controlled thyristors, BCTs), as shown in figure 3.

For the forward power flow from station 13 to station 14, the operation process is similar to the embodiment according to figure 1, where power switches T1a, T3b, T2a, T4b respectively correspond to power switches T1, T3, T2, T4 in figure 1. For the reverse power flow from station 14 to Station 13, the operation process is similar but thyristor T1a, T3b, T2a, T4b will be used instead of T1b, T3a, T2b and T4a.

Though the present invention has been described on the basis of some preferred embodiments, those skilled in the art should appreciate that those embodiments should by

no way limit the scope of the present invention. Without departing from the spirit and concept of the present invention, any variations and modifications to the embodiments should be within the apprehension of those with ordinary knowledge and skills in the art, and therefore fall in the scope of the present invention which is defined by the accompanied claims.

WHAT IS CLAIMED IS:

1. A DC system converted from an AC system with phase line A, phase line B and phase line C, including:

5 a first converter station and a second converter station connected by a first phase line and a second phase line selected from the phase line A, the phase line B and the phase line C for transmission of DC power therebetween;

a first leg being arranged to connect across DC side of the first converter station, having a first controllable power switch in its upper leg and a second controllable power switch in its lower leg, which are connected in series via a first middle point;

10 a second leg being arranged to connect across DC side of the second converter station, having a third controllable power switch in its upper leg and a fourth controllable power switch in its lower leg, which are connected in series via a second middle point;

15 a bi-directional power switch, being arranged in a third phase line selected from the phase line A, the phase line B and the phase line C; and

a controller;

wherein:

20 the third phase line is arranged to connect the first middle point and the second middle point; and

the controller is configured to turn on the bi-directional power switch and both of the controllable power switches in the respective upper/lower legs so as to allow a current to flow through them.

2. The DC system according to claim 1, further including:

25 at least one snubber respectively connected in parallel with at least one of the first, second, third and fourth controllable power switches.

3. The DC system according to claim 1 or 2, further including:

a voltage sensor is configured to measure voltage level at the third phase line;

the controller is further configured to turn on both of the bi-directional power switch and one of the both of the controllable power switches in the respective upper/lower legs, and in response to that the measurement of the voltage level reaches a predetermined value turn on the other controllable power switch.

- 5 4. The DC system according to claim 3, wherein:
the voltage sensor is arranged in the first converter station or the second converter station.
- 10 5. The DC system according to claim 1 or 2, wherein:
the controller is further configured to control the bi-directional power switch, the first, second, third and fourth controllable power switches to make the first phase line and the third phase line share the direct current between the first converter station and the second converter station in one direction during a period of time followed by a corresponding period of time in which the second phase line and the third phase line are sharing the current between the first converter station and the second converter station in the opposite direction.
- 15 6. The DC system according to any of the preceding claims, wherein:
the bi-directional power switch has two IGBT/IGCT units connected in anti-series.
- 20 7. The DC system according to any of the preceding claims, wherein:
the first, second, third and fourth controllable power switch each has two thyristors connected in anti-parallel.
- 25 8. The DC system according to any of the preceding claims, further including:
a surge arrester connected with the bi-directional power switch in parallel.
9. A method for controlling a DC system converted from an AC system with phase line A, phase line B and phase line C, wherein:
the DC system includes:
a first converter station and a second converter station connected by a first phase line and a second phase line selected from the phase line A, the phase line B and the phase line C;

a first leg being arranged to connect across DC side of the first converter station, having a first controllable power switch in its upper leg and a second controllable power switch in its lower leg, which are connected in series via a first middle point;

a second leg being arranged to connect across DC side of the second converter station, having a third controllable power switch in its upper leg and a fourth controllable power switch in its lower leg, which are connected in series via a second middle point;

a bi-directional power switch, being arranged in a third phase line selected from the phase line A, the phase line B and the phase line C; and

the third phase line is arranged to connect the first middle point and the second middle point;

the method includes:

turn on the bi-directional power switch and both of the controllable power switches in the respective upper/lower legs so as to allow a current to flow through them.

10. The method according to claim 9, wherein:

the DC system further includes a voltage sensor is configured to measure voltage level at the third phase line; and

the turning-on of both of the bi-directional power switch and one of the both of the controllable power switches in the respective upper/lower legs is followed by the turning-on of the other controllable power switch in response to that the measurement of the voltage level reaches a predetermined value.

11. The method according to claim 9 or 10, further including:

controlling the bi-directional power switch, the first, second, third and controllable power switches to make the first phase line and the third phase line share the direct current between the first converter station and the second converter station in one direction during a period of time followed by a corresponding period of time in which the second phase line and the third phase line are sharing the current between the first converter station and the second converter station in the opposite direction.

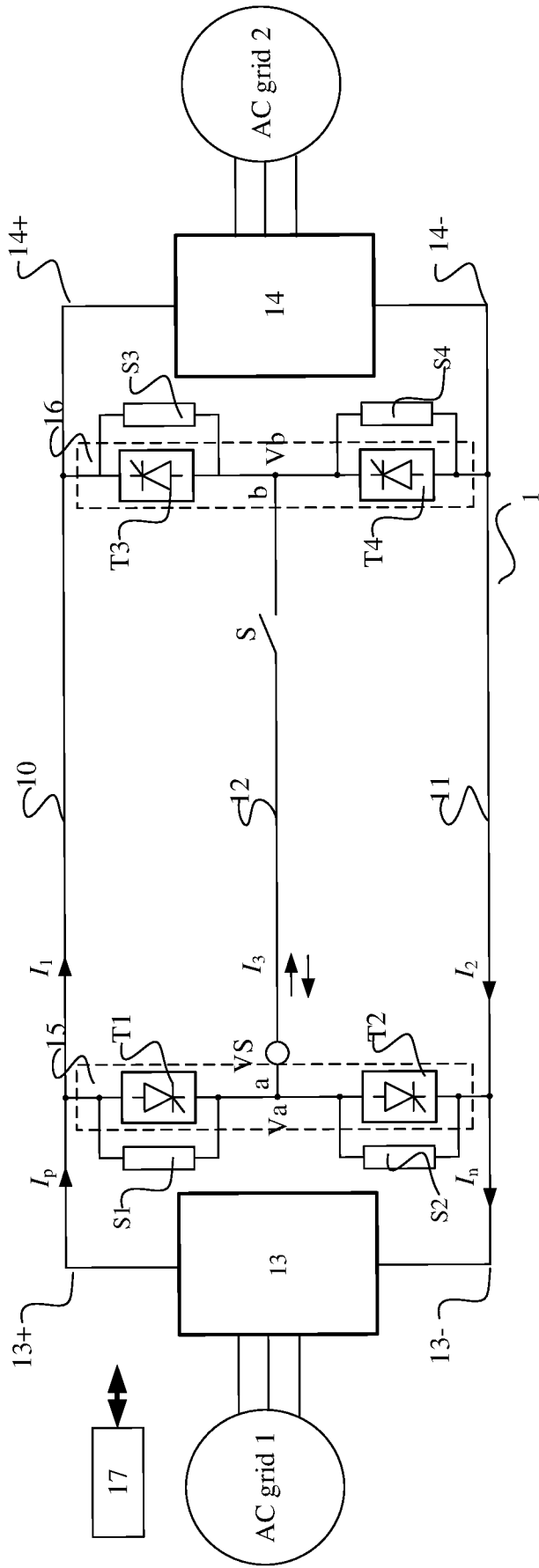


Figure 1

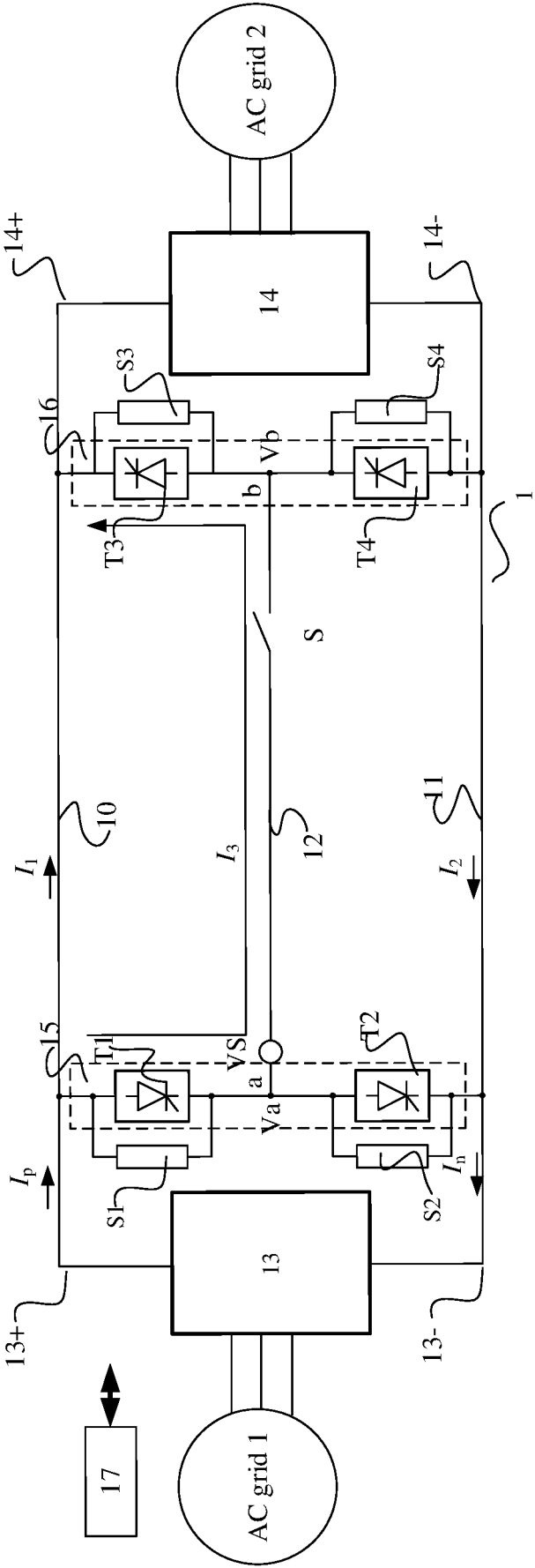


Figure 2A

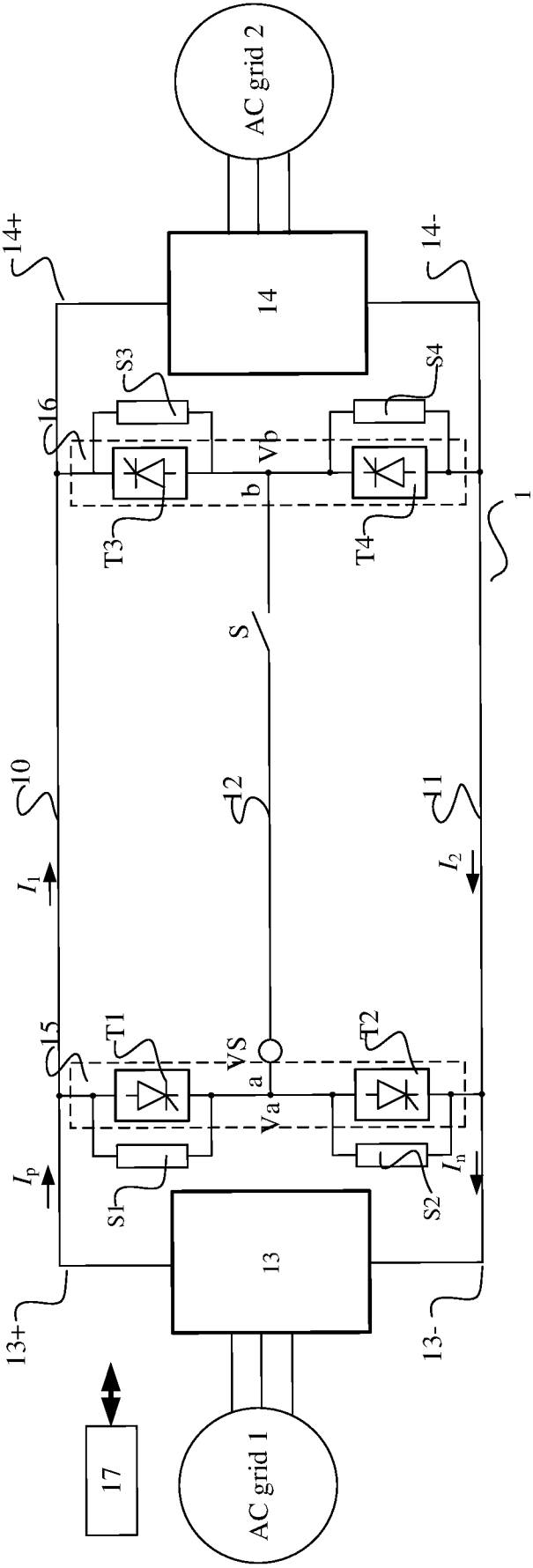


Figure 2B

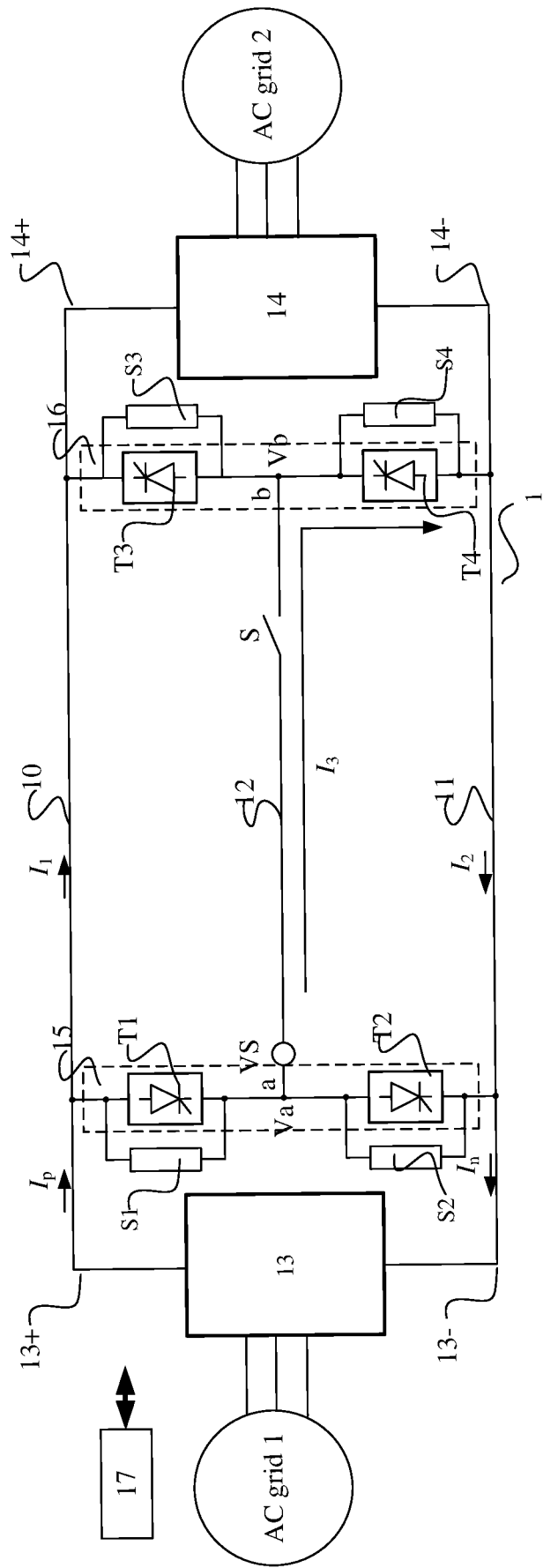


Figure 2C

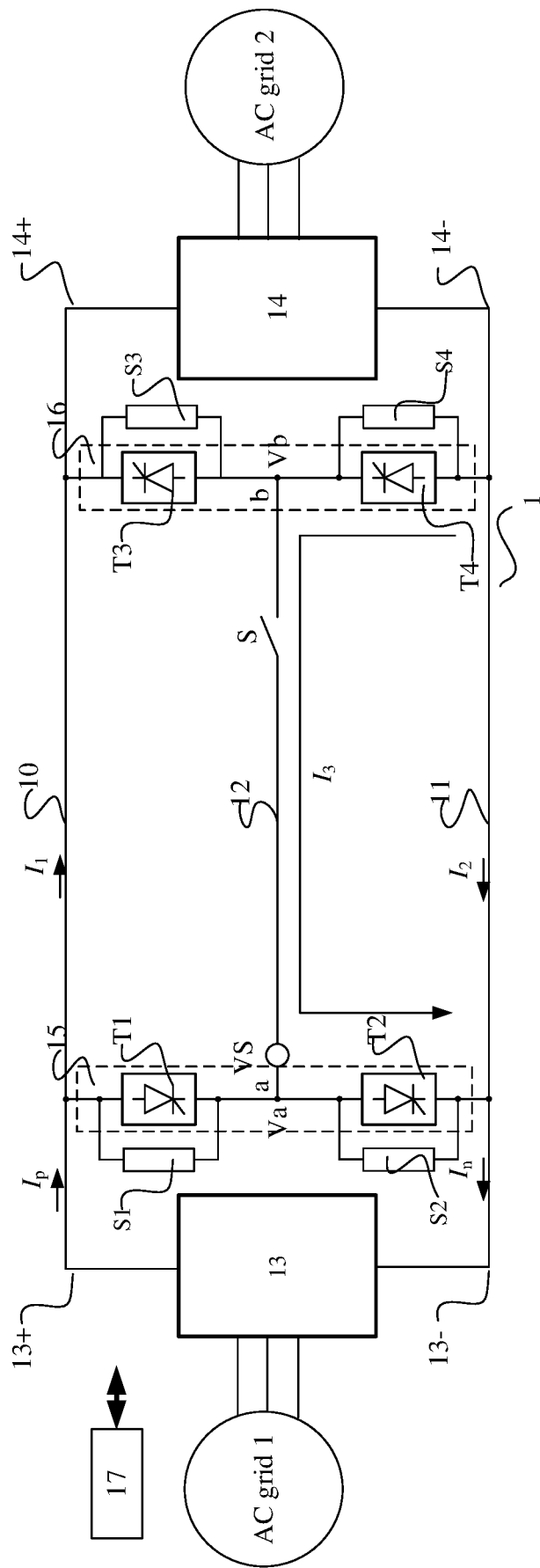


Figure 2D

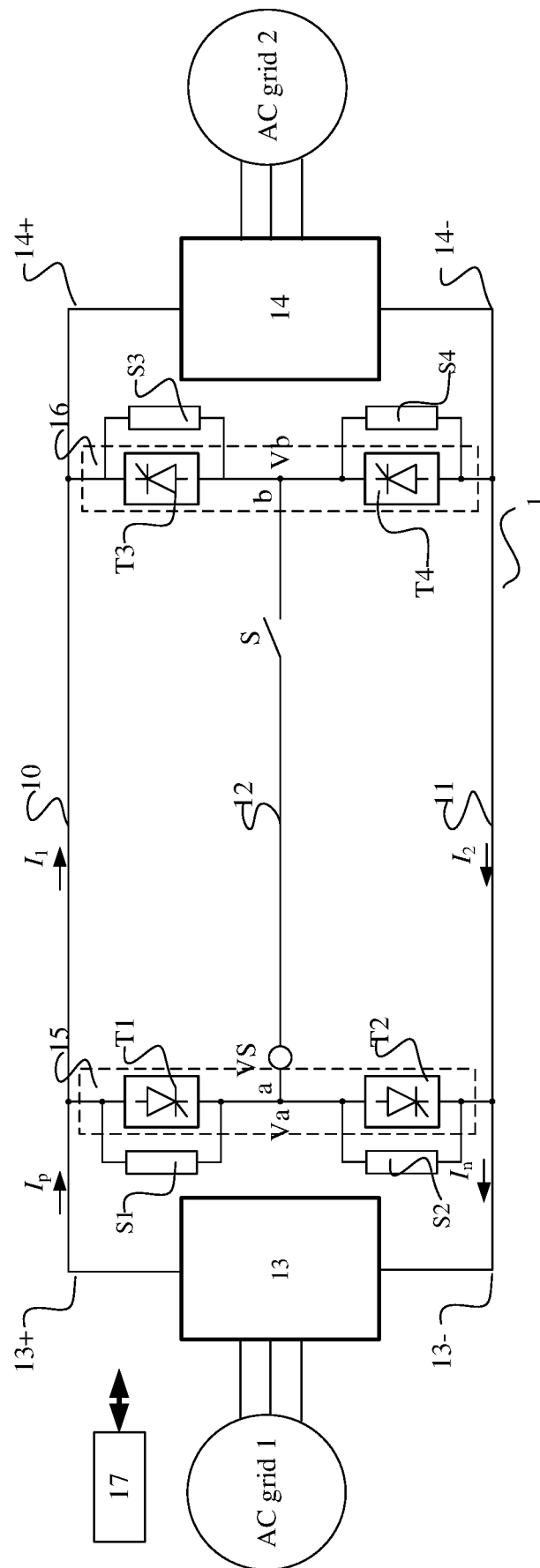


Figure 2E

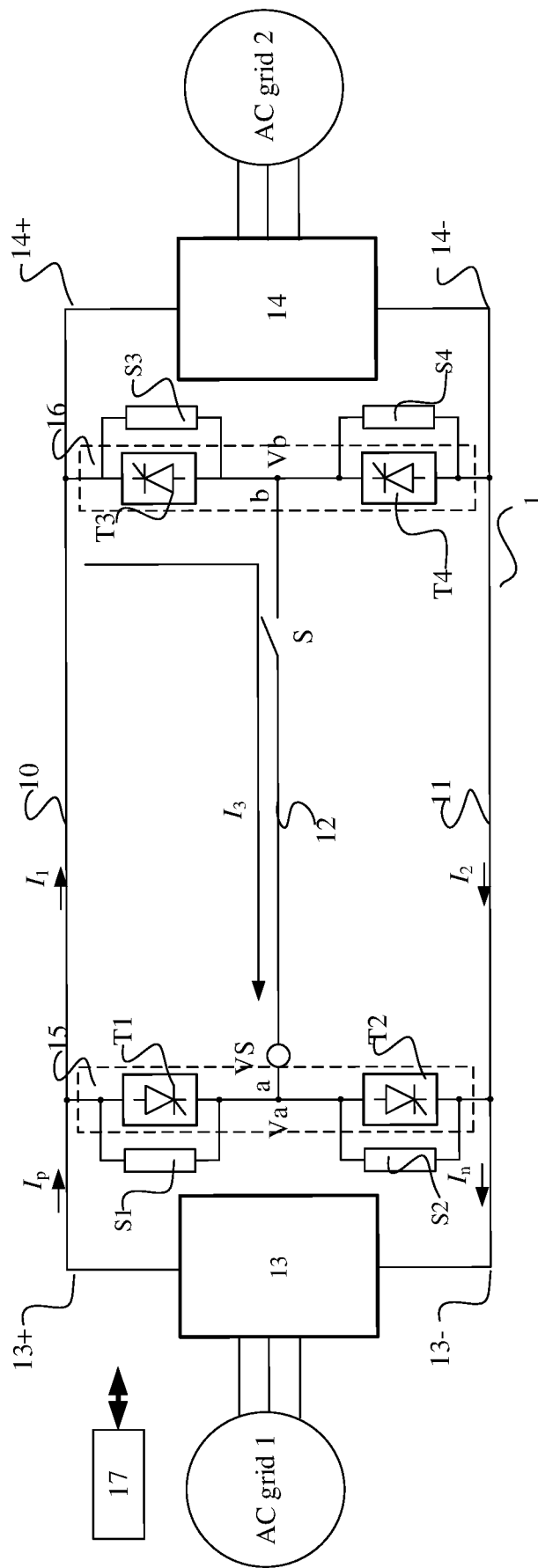


Figure 2F

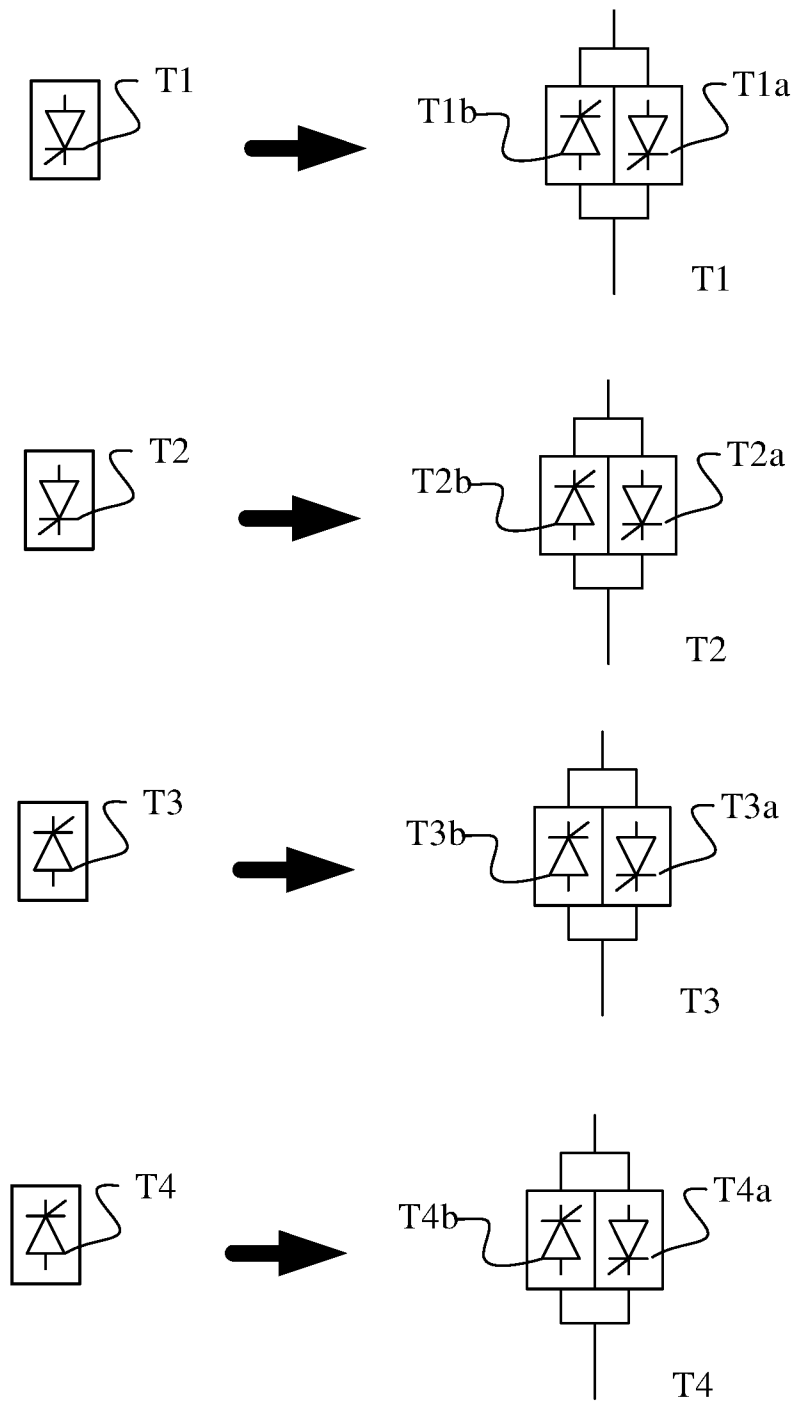


Figure 3

INTERNATIONAL SEARCH REPORT

International application No.

PCT/CN2019/091358

A. CLASSIFICATION OF SUBJECT MATTER

H02J 3/36(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)

H02J, H02M

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

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

CNPAT, CNKI, EPODOC, WPI: HVDC, VSC, three-pole, tri-pole, overcurrent, capacitor, parallel, discharge

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	CN 103595064 A (ZHEJIANG UNIVERSITY) 19 February 2014 (2014-02-19) description, paragraphs [0049]-[0065] and figures 3, 6, 7	1-11
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Further documents are listed in the continuation of Box C.



See patent family annex.

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Date of the actual completion of the international search

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Date of mailing of the international search report

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INTERNATIONAL SEARCH REPORT
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