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EP 2458725 A2
CN 105099206 A
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CN 104601003 A

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(54) Title of the Invention: **A subsea DC to DC voltage converter**
Abstract Title: **Subsea DC-DC voltage converter**

(57) A subsea DC-DC voltage converter comprising a DC-AC converter 31 and an AC-DC converter 34. The DC-AC converter comprises first 35 and second 36 voltage supply lines between which first 37 and second 38 conversion lines extend. At least one of the conversion lines 37, 38 comprises a plurality of switching stages 14, each switching stage being adapted to be switched between an open configuration in which it has a capacitive input impedance (17, Figs. 3a&3b) and a closed configuration in which switching stage is a closed circuit at DC. A controller 40 controls the switching stages to produce a periodic time varying voltage difference between the first and second output lines. The AC-DC voltage conversion stage 34 comprises a transformer (43, Fig. 7) comprising a primary coil (44, Fig. 7) and at least one secondary coil (45, Fig. 7) the secondary coil(s) (45, Fig. 7) being connected to AC-DC converter(s) (46, Fig. 7). The voltage source (2, Fig. 1) may be connected to the first and second voltage lines via an umbilical cord (5, Fig. 1). The controller switches the switching stages such that: a square wave is output; and no switching stage experiences a voltage greater than the stage's breakdown voltage. The switching stages may be a full or half bridge switching stage. The second conversion line may comprise a plurality of capacitors 39 or switching stages connected in series. A low pass filter maybe connected to the output of the rectifier (AC-DC converter).

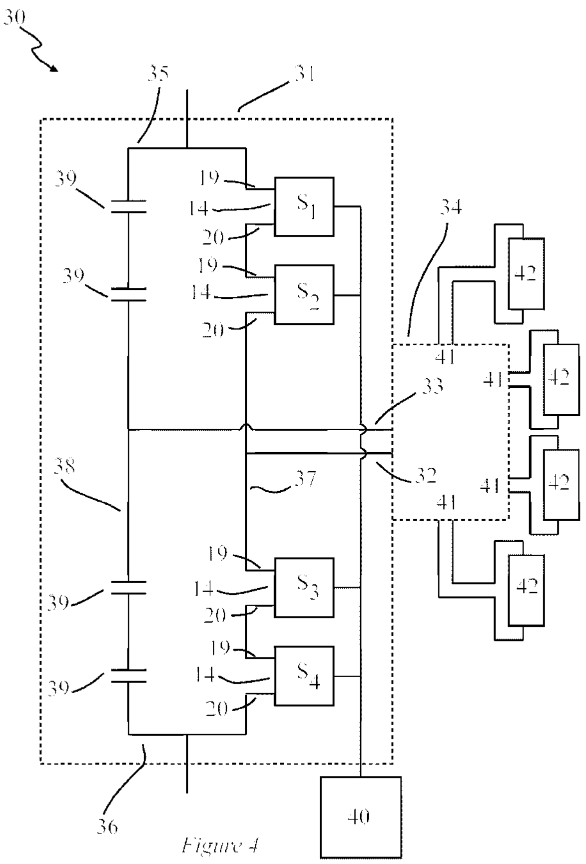

Figure 4

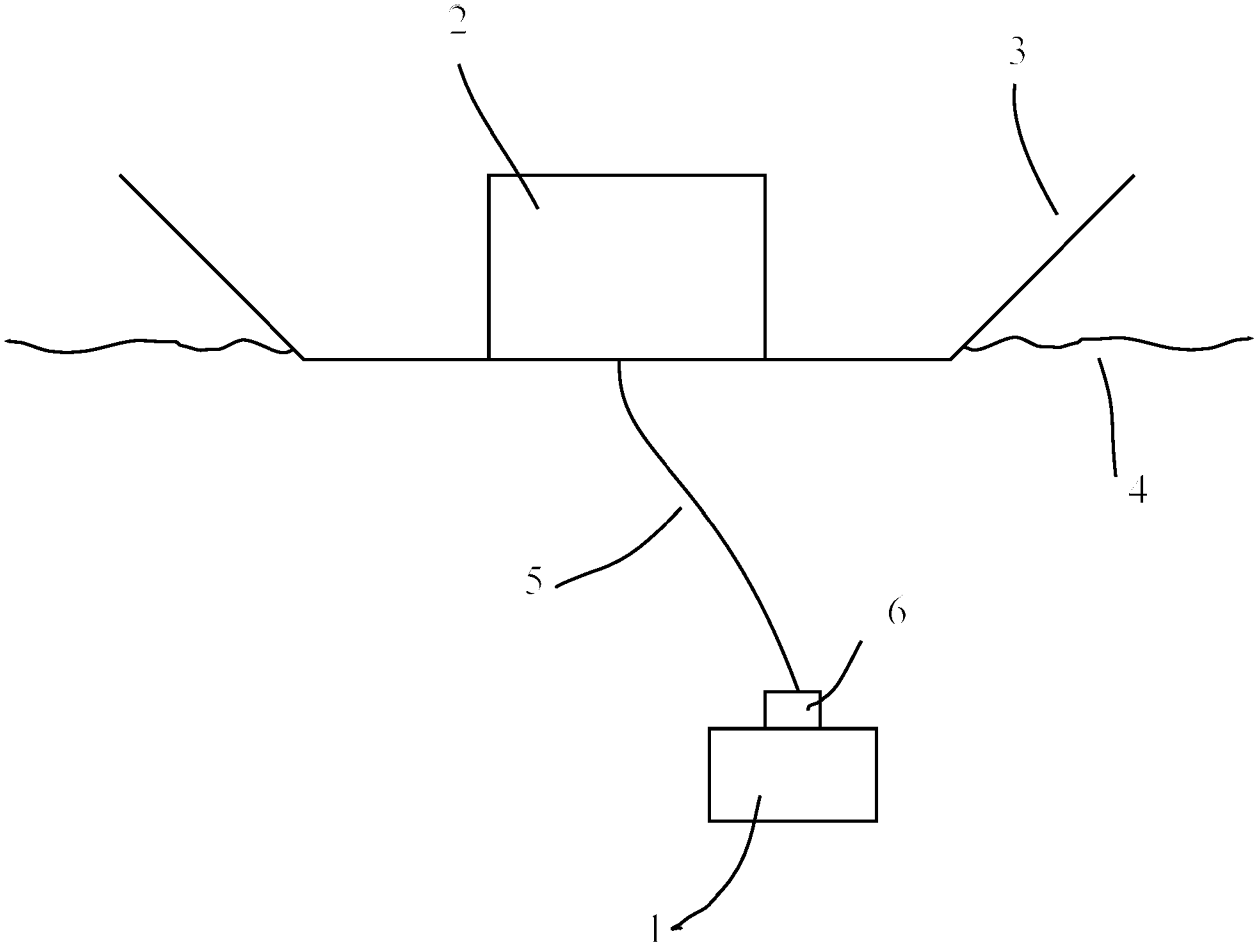

Figure 1

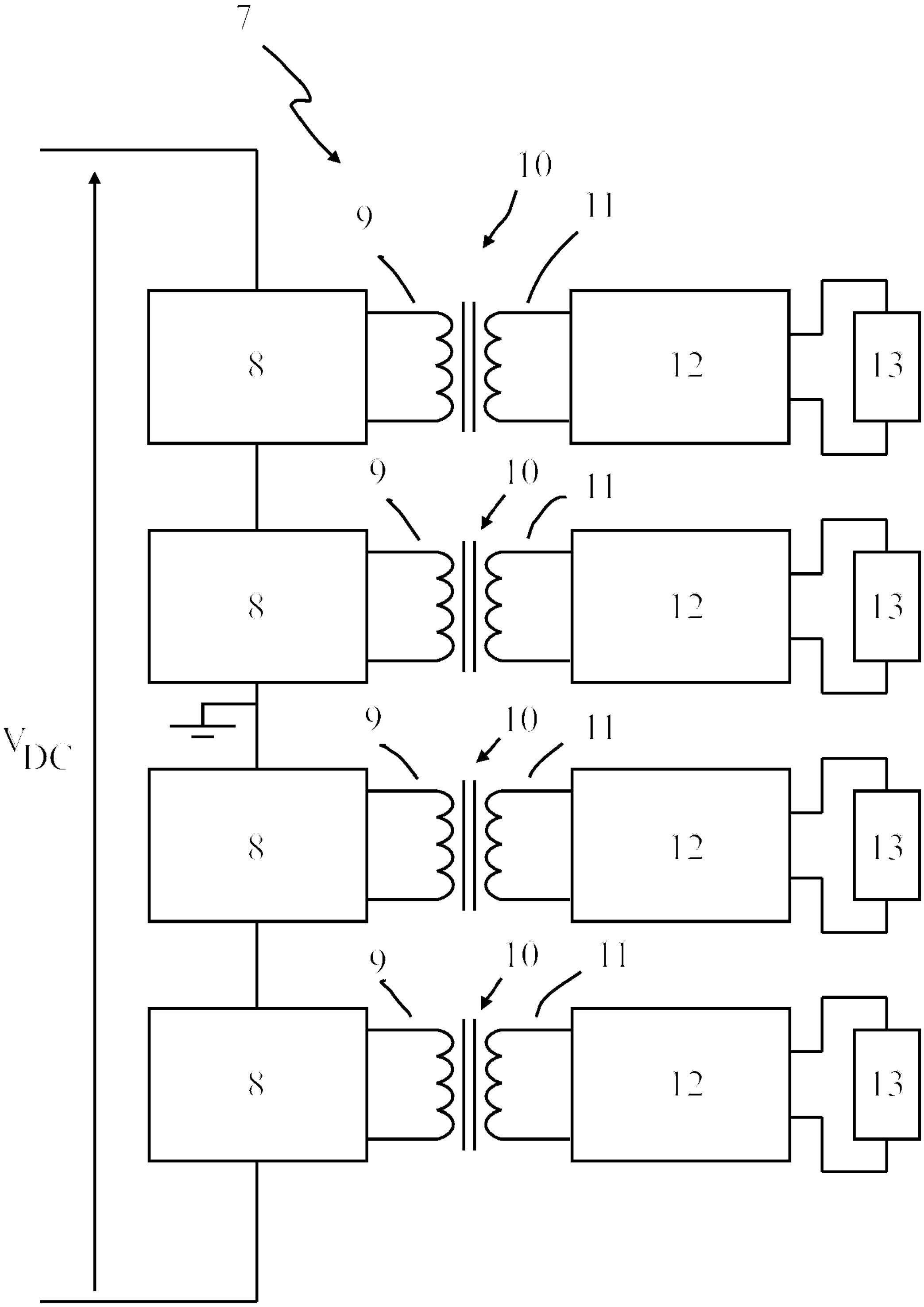

Figure 2

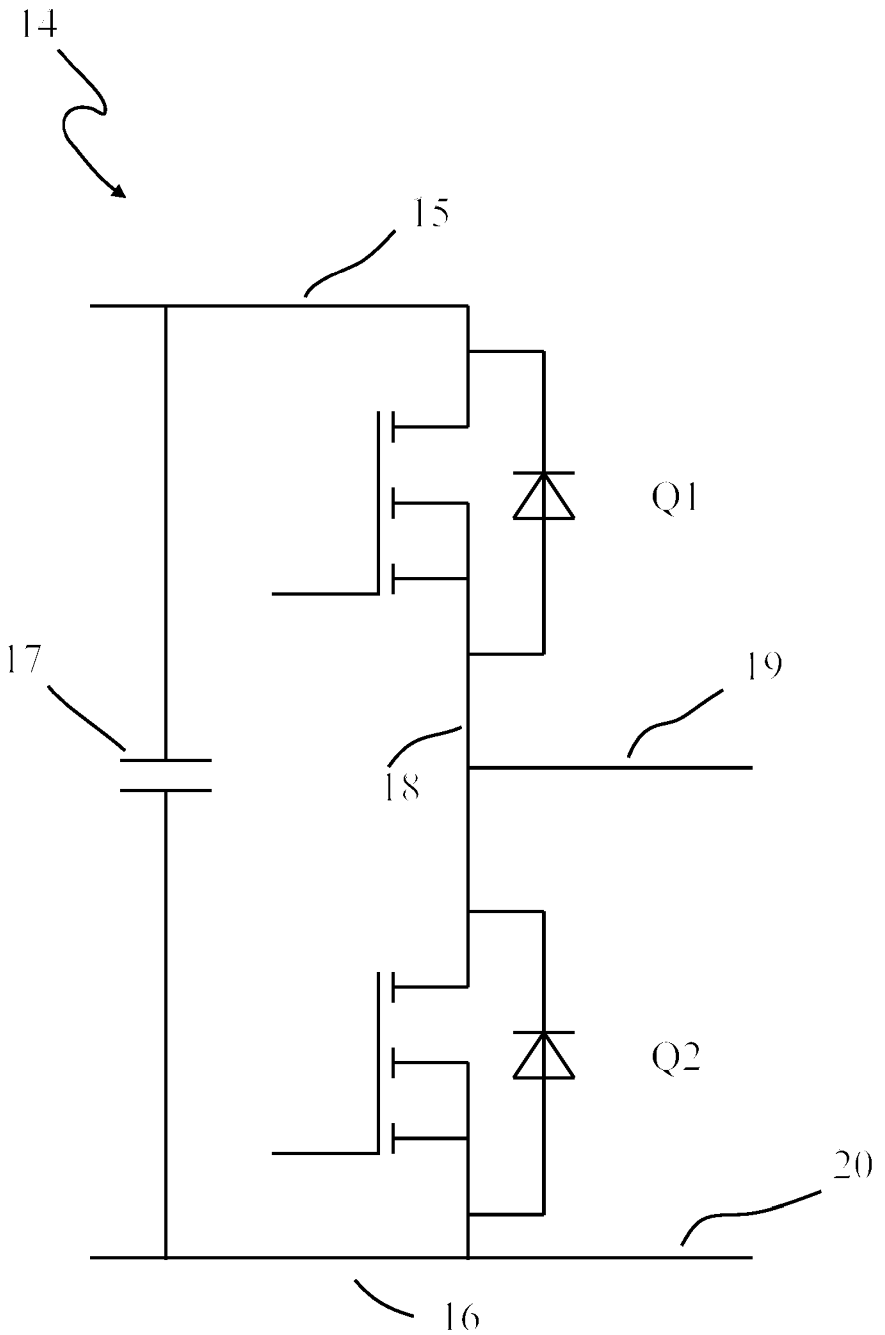

Figure 3(a)

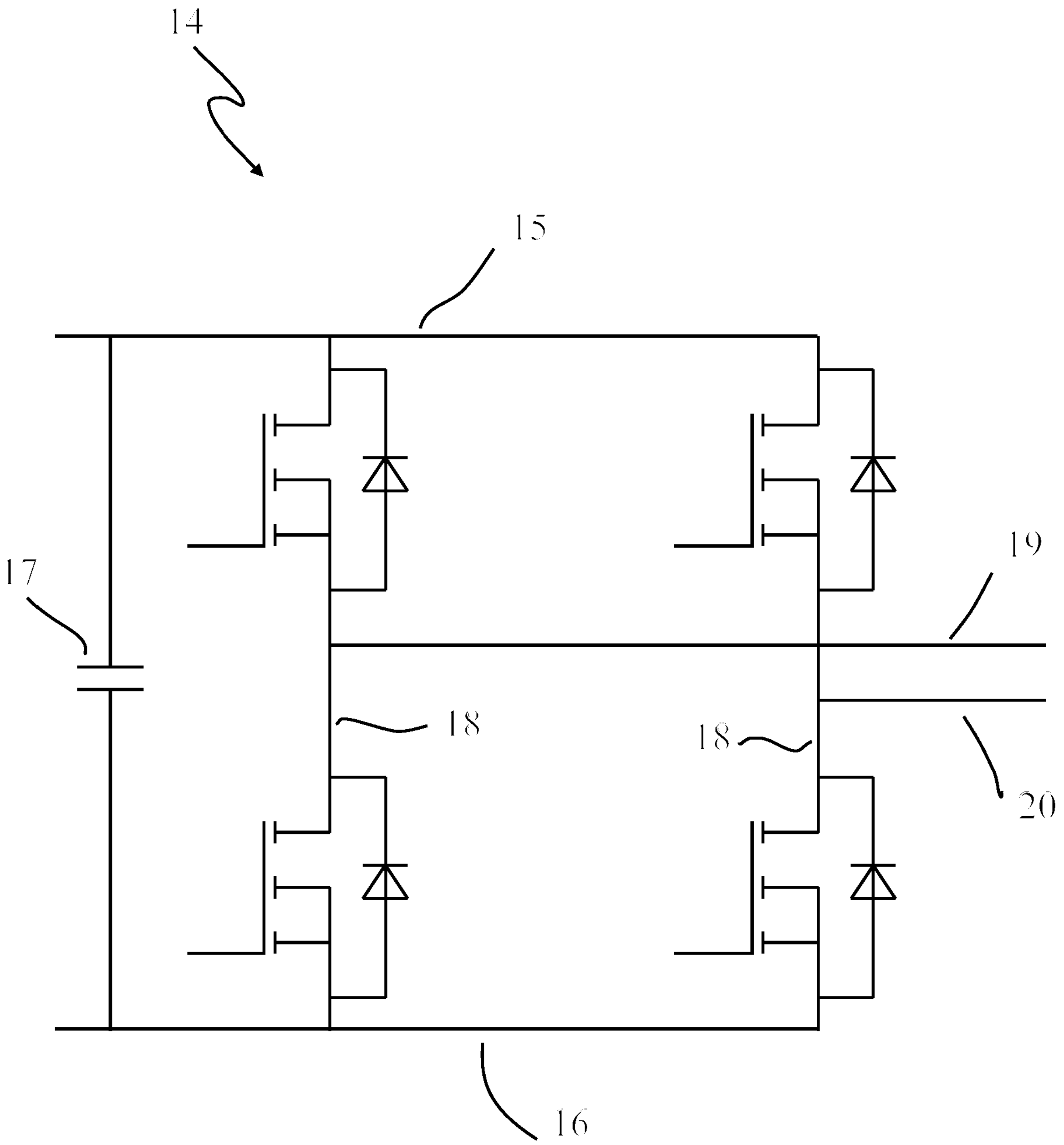

Figure 3(b)

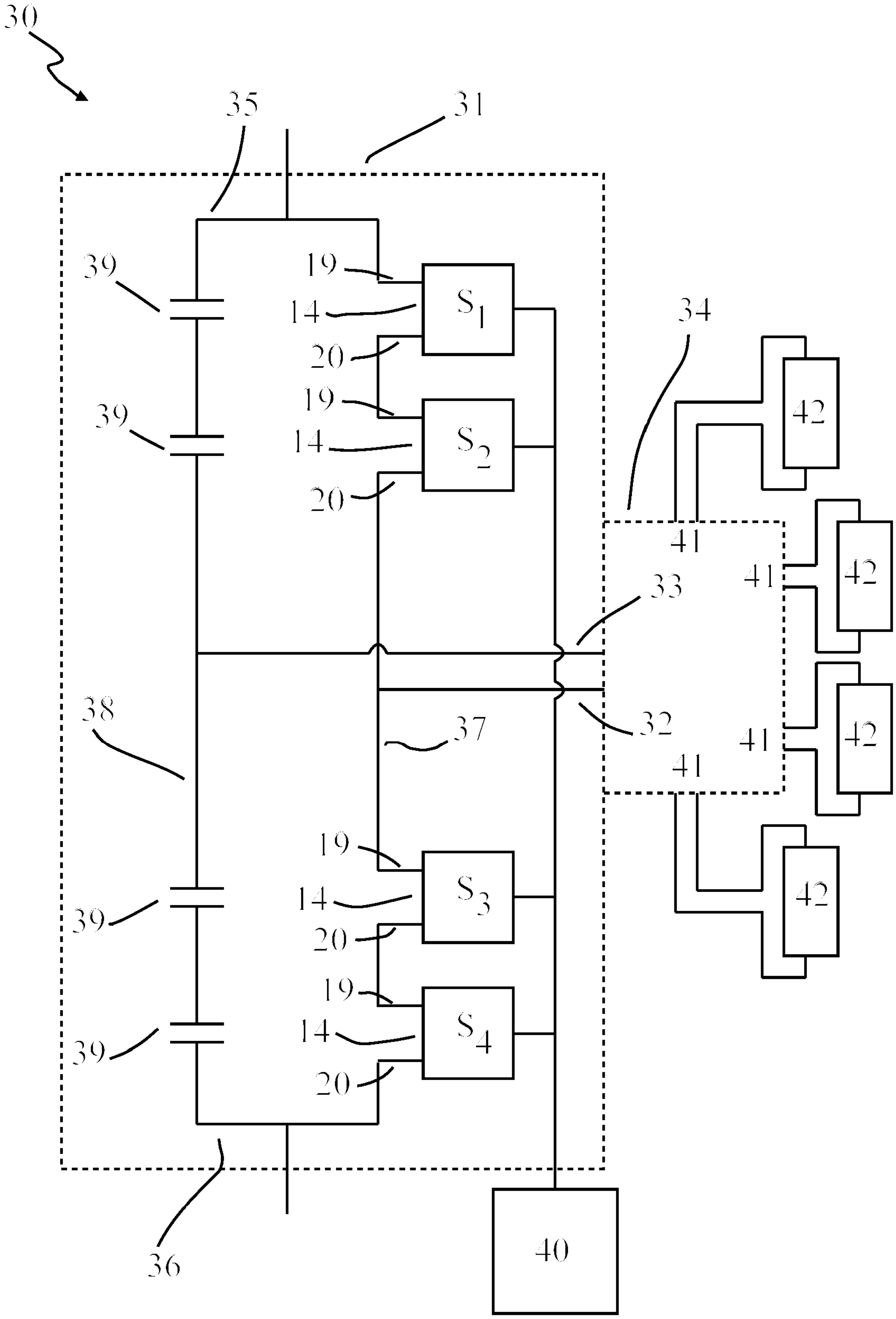
30
35
31
39
19
S1
14
20
19
S2
14
20
39
34
42
41
42
41
33
42
32
41
41
37
38
42
19
S3
14
39
20
19
S4
14
39
20
36
40

Figure 4

Switch	Step 1	Step 2	Step 3	Step 4
S_1	Open	Closed	Closed	Open
S_2	Open	Open	Closed	Closed
S_3	Closed	Open	Open	Closed
S_4	Closed	Closed	Open	Open
V_{out}	V	0.5V	0	0.5V

Figure 5

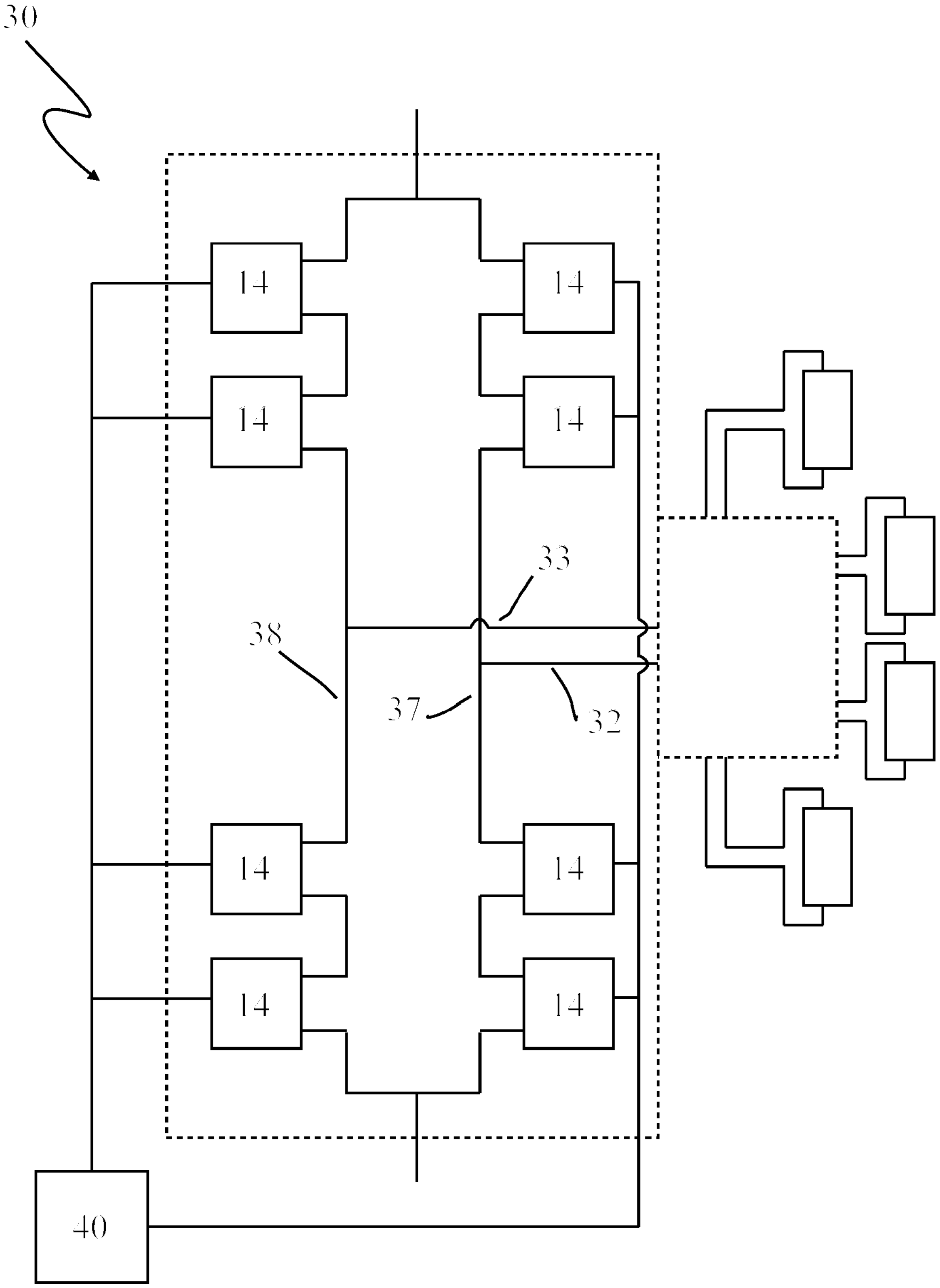

Figure 6

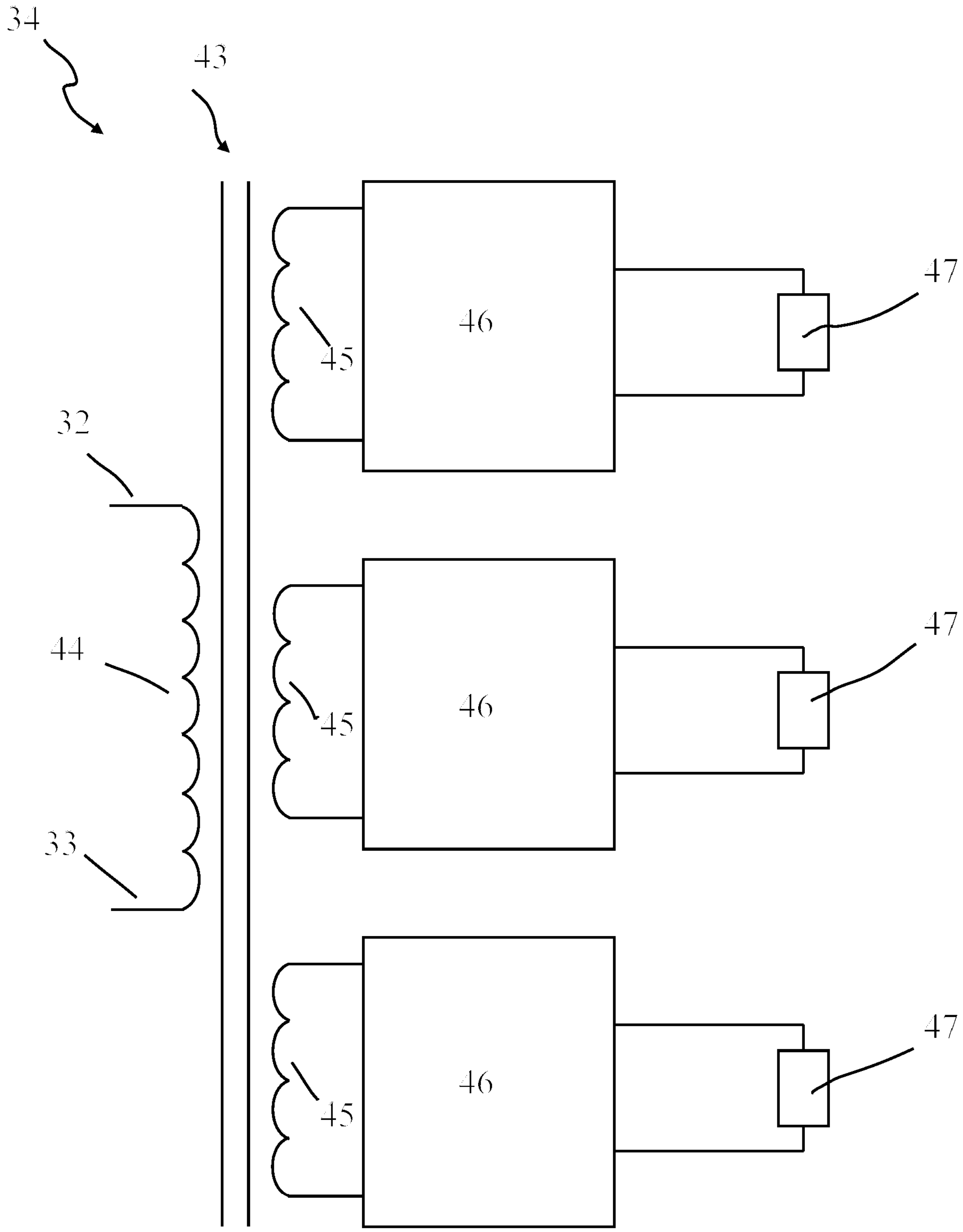

Figure 7

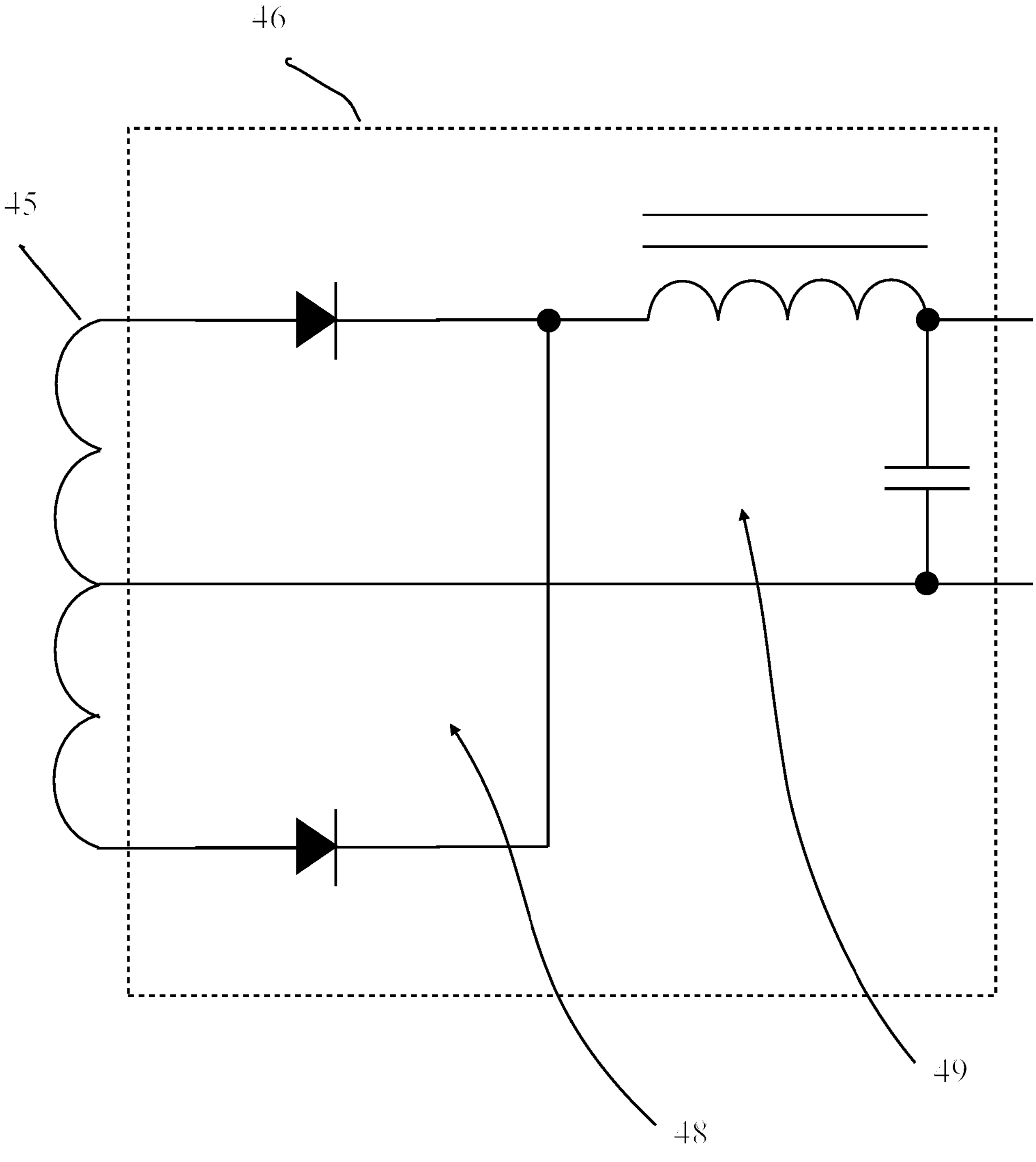

Figure 8

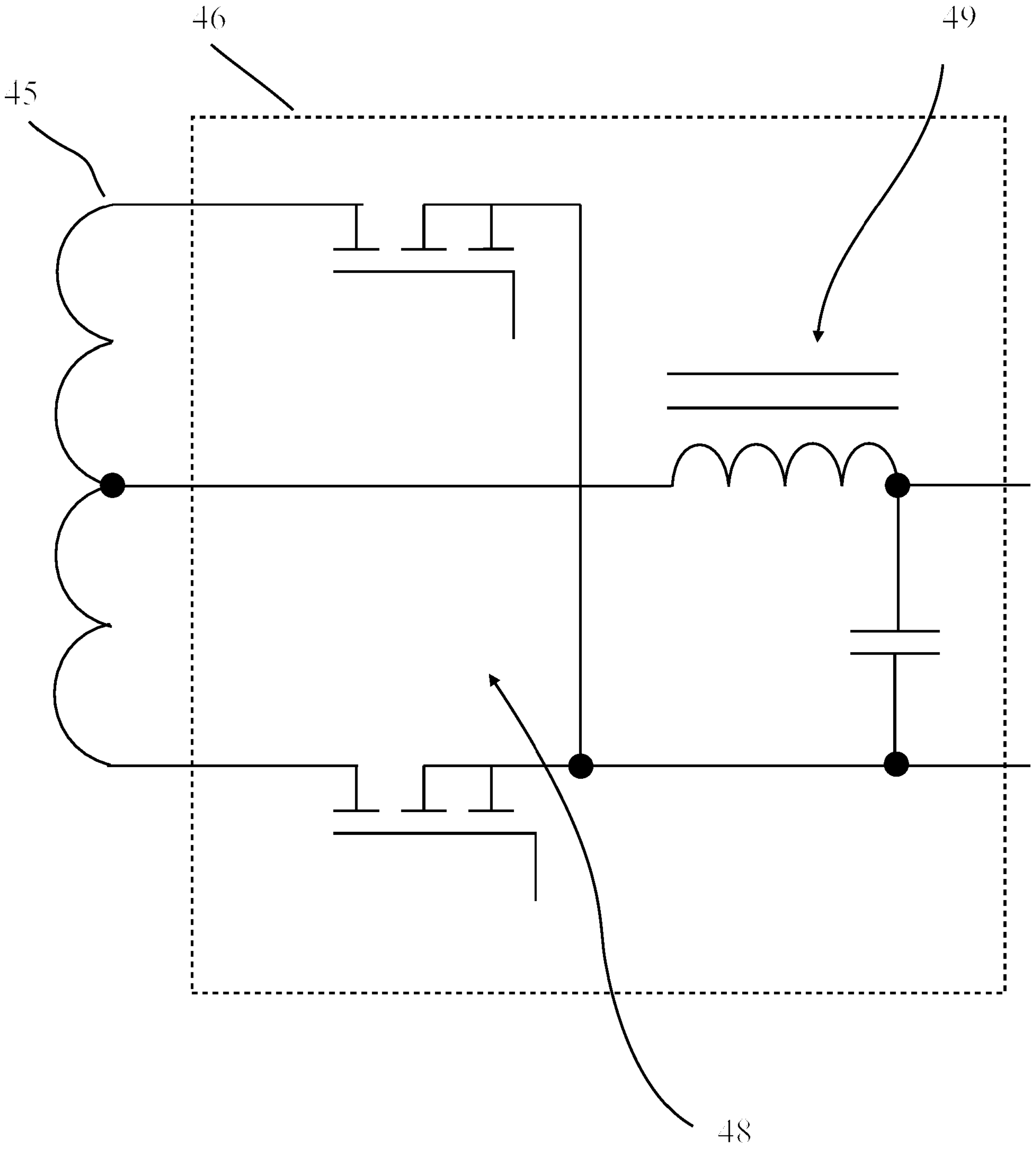

Figure 9

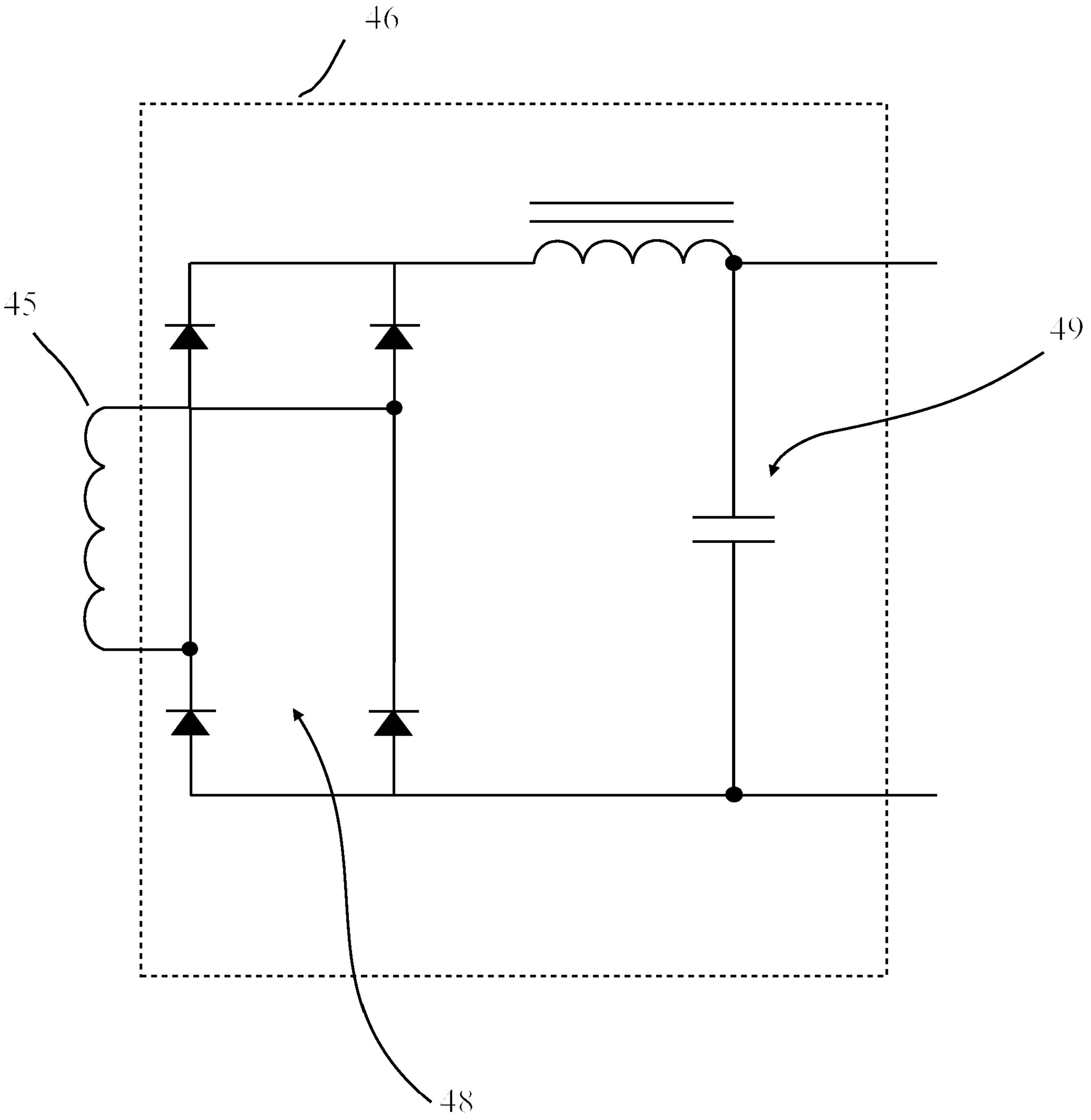

Figure 10

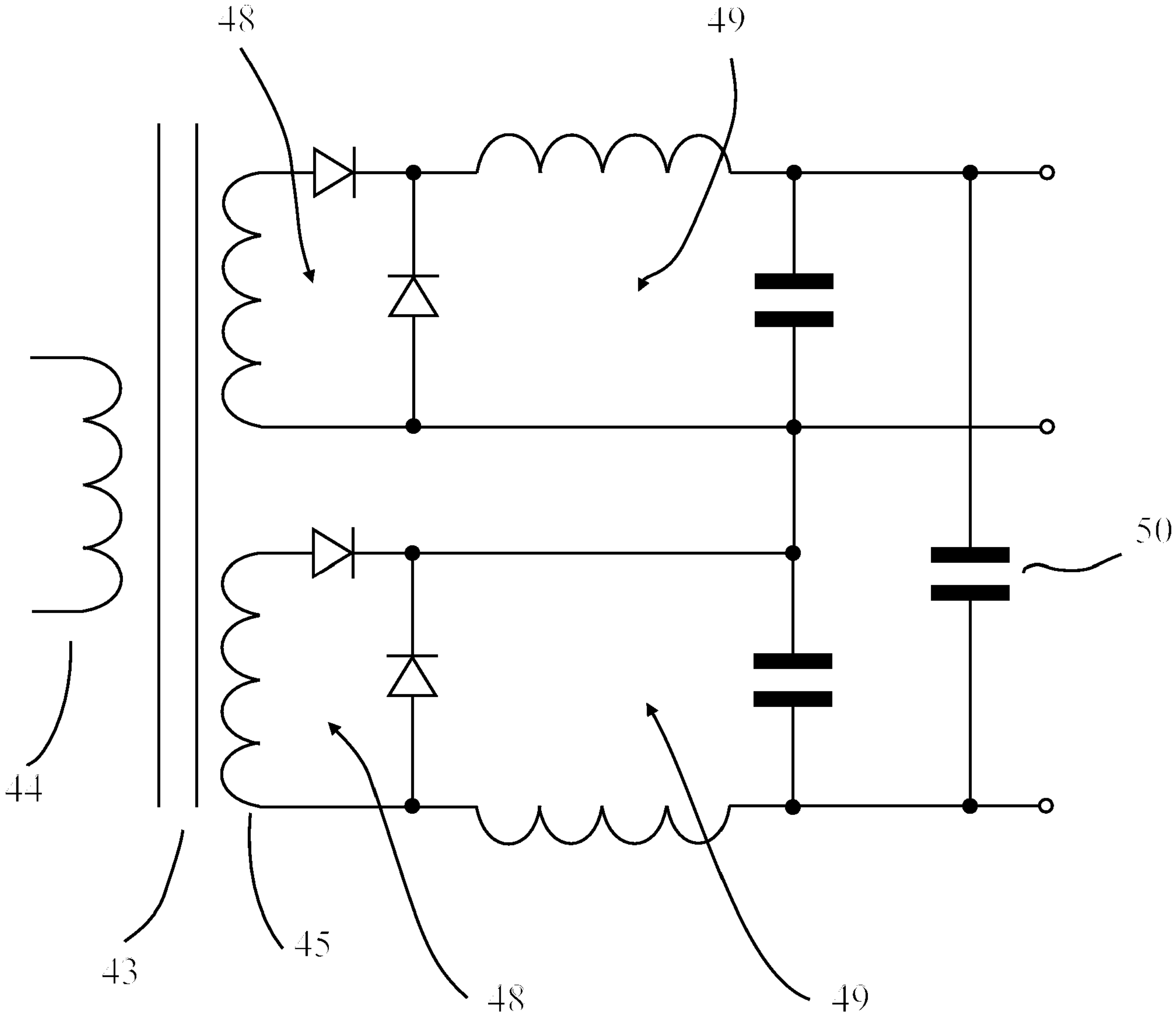

Figure 11

A subsea DC to DC voltage converter

The present invention relates to a subsea DC to DC voltage converter. More particularly, but not exclusively, the present invention relates to a subsea DC to DC voltage converter comprising an AC to DC conversion stage which comprises first and second conversion lines, at least one conversion line comprising a plurality of switching stages connected together in a series chain, the DC to DC voltage converter further comprising a controller connected to the switching stages, the controller being adapted to switch the switching stages between open and closed configurations to produce a time varying voltage on an output line arranged part way along the conversion line. Preferably the controller switches the switching stages in a balanced pattern .

DC to DC voltage converters are known. Such DC to DC converters typically comprise a plurality of DC to AC converters connected together in a stack configuration such that a received DC voltage is split equally between them. Each DC to AC converter converts its portion of the received DC voltage into a time varying (AC) voltage. Each AC voltage is then passed to a step-down transformer and then to an AC to DC voltage converter which performs some form of rectification and low pass filtering. The resulting DC voltage is then passed to a load.

A problem with such an arrangement is load balancing. The loads connected to the DC to AC converters must be substantially equal for the DC to DC voltage converter to operate correctly. If one of the loads is changed this affects the operation of the remaining DC to AC converters in the stack. This is undesirable.

The present invention seeks to overcome the problems of the prior art.

Accordingly the present invention provides a subsea DC to DC voltage converter comprising

a DC to AC voltage conversion stage comprising first and second output lines,

an AC to DC voltage conversion stage connected to the first and second outputs lines;

the DC to AC voltage conversion stage comprising

first and second voltage supply lines;

first and second conversion lines extending in parallel between the voltage supply lines;

at least one of the conversion lines comprising a plurality of switching stages, each switching stage comprising first and second switching stage outputs, each switching stage being adapted to be switched between an open configuration in which it has a capacitive input impedance between the two switching stage outputs and a closed configuration in which the two switching stage outputs are closed circuit at DC, the switching stages being connected together in a series chain with the first switching stage output of each switching stage being connected to the second switching stage output of the previous switching stage in the chain;

the first output line connected to the first conversion line part way along its length; and,

the second output line connected to the second conversion line part way along its length;

the AC to DC voltage conversion stage comprising

a transformer comprising a primary coil and at least one secondary coil, the primary coil being connected to the first and second output lines, the at least one secondary coil being connected to a voltage conversion module for converting the received time varying voltage to a DC voltage;

the subsea DC to DC voltage converter further comprising a controller connected to the switching stages for switching the switching stages between open and closed configurations to produce a periodic time varying voltage difference between the first and second output lines.

The subsea DC to DC voltage converter according to the invention can supply a DC voltage to a number of different loads of different sizes without becoming unbalanced.

Preferably each switching stage is a full bridge switching stage or a half bridge switching stage.

Each switching stage can be a full bridge switching stage.

Alternatively each switching stage can be a half bridge switching stage.

Preferably the controller switches the switching stages in a pattern resulting in a square wave voltage between the first and second output lines.

Preferably the controller switches the switching stages such that no switching stage experiences a voltage difference between its first and second switching stage outputs greater than the breakdown voltage of the switching stage.

Preferably the voltage conversion module comprises a rectifier connected to the secondary coil.

Preferably the voltage conversion module further comprises a low pass filter connected to the output of the rectifier.

Preferably the transformer of the AC to DC conversion stage comprises a plurality of secondary coils each having a voltage conversion module connected thereto.

Preferably the first conversion line comprises a plurality of switching stages connected together in a series chain, the first output line being arranged such that it has at least one, preferably two switching stages on each side.

Preferably the first output has an equal number of switching stages on each side.

Preferably the second conversion line comprises a plurality of capacitors connected in series, the second output line being connected such that it has at least one capacitor on each side.

Preferably the second conversion line comprises a plurality of switching stages connected together in a series chain, the second output line being arranged such that it has at least one, preferably two switching stages on each side.

Preferably the second output line has an equal number of switching stages on each side.

Preferably the first and second conversion lines comprise an equal number of switching stages, the first and second output lines being arranged in identical positions along their respective conversion lines.

Preferably each switching stage comprises a capacitor which provides the capacitive input impendence when the switching stage is in the open configuration, the controller being adapted to switch the switching stages in a balanced pattern such that the voltage across each capacitor remains substantially constant.

Preferably the subsea DC to DC voltage converter further comprises a DC voltage source connected across the first and second voltage supply lines.

Preferably the voltage source is connected to the first and second voltage lines via an umbilical cord.

The present invention will now be described by way of example only and not in any limitative sense with reference to the accompanying drawings in which

Figure 1 shows a subsea electrical device in use;

Figure 2 shows a known DC to DC voltage converter in more detail;

Figure 3(a) shows a first embodiment of a switching stage of a DC to DC voltage converter according to the invention;

Figure 3(b) shows a further embodiment of a switching stage of a DC to DC voltage converter according to the invention;

Figure 4 shows a first embodiment of a subsea DC to DC voltage converter according to the invention;

Figure 5 shows a switching pattern of the switching stages of a DC to DC converter according to the invention;

Figure 6 shows a further embodiment of a subsea DC to DC voltage converter according to the invention;

Figure 7 shows an embodiment of the AC to DC voltage conversion stage of a subsea DC to DC voltage converter according to the invention in greater detail;

Figure 8 shows an embodiment of an AC to DC voltage conversion module of the AC to DC voltage conversion stage of figure 7;

Figure 9 shows a further embodiment of an AC to DC voltage conversion module of the AC to DC voltage conversion stage of figure 7;

Figure 10 shows a further embodiment of an AC to DC voltage conversion module of the AC to DC voltage conversion stage of figure 7; and,

Figure 11 shows a further embodiment of an AC to DC voltage conversion stage of a DC to DC voltage converter according to the invention.

Shown in figure 1 is a subsea electrical device 1 in use. The subsea electrical device 1 is an ROV 1. The ROV 1 comprises a number of electrical systems such as motors, lights, tooling etc. The power requirements of these systems depend on the system. Instruments and lights typically require a 10KW power supply. Hydraulic motor drives and tooling typically require a 50KW power supply.

The ROV 1 is connected to a DC power supply 2 arranged on a ship 3 at the sea surface 4 by means of an electrically conducting umbilical cable 5. The DC power supply 2 typically provides a DC voltage in the medium voltage range of around 3000 – 5000 volts.

The systems of the ROV typically require power at around 120 Volts. Accordingly, a step-down DC to DC voltage converter 6 is arranged between the end of the umbilical cord 5 and the ROV 1. The DC to DC voltage converter 5 converts the input DC voltage into a plurality 120 Volt DC outputs. Each system is connected to a separate DC output.

Shown in figure 2 is a known step-down DC to DC voltage converter 7. The DC to DC voltage converter 7 comprises a plurality of DC to AC voltage converters 8 arranged in a stack configuration such that that incident DC voltage is divided equally between them. The output from each DC to AC converter 8 is connected to the primary coil 9 of a step-down transformer 10. Connected to the secondary coil 11 of the step-down transformer 10 is an AC to DC converter 12. The AC to DC converter 12 rectifies the AC voltage received from the step-down transformer 10 and then passes it through a low pass filter to produce an output DC voltage. A separate load 13 is connected to the output of each of the AC to DC converters 12.

Such a DC to DC voltage converter 7 works well when each AC to DC converter 12 is loaded equally. With an ROV however some systems require more power than others. In this case the DC to DC voltage converter 7 becomes unbalanced which is undesirable. In such a configuration, the only means of protecting the individual switching cells 8 from exceeding their voltage limits is by ensuring the current flowing through each stage is identical. For the two-level system shown in figure 2 at, for example, 2000 Volts DC input with a balanced load would give an identical current through each cell 8 meaning the input voltage would be shared evenly (1000 Volts DC) across each cell 8. If the load was to become imbalanced the current distribution would be changed and the input voltage sharing would be disrupted forcing a switching stage above its operating limits potentially causing a breakdown failure.

Shown in figure 3(a) is a switching stage 14 of a subsea DC to DC voltage converter according to the invention. The switching stage 14 is a half bridge switching stage 14. The operation of half bridge switching stages is well known in the art and so will only briefly be described. The half bridge switching stage 14 comprises first and second support lines 15,16. Extending between the support lines 15,16 is a capacitor 17. Also extending between the support lines 15,16 is a control line 18. The control line 18 comprises two field effect transistors (FETS). Q1, Q2, connected together in series. Each FET Q1, Q2 is typically a compound semiconductor MOSFET. The compound semiconductor is typically Silicon Carbide or Gallium Nitride. Other wide bandgap semiconductor such as diamond can also be employed. Wide bandgap typically means a bandgap greater than 2eV, more preferably greater than 3eV. The use of wide bandgap FETs enables the device to operate at higher frequencies so reducing the size and weight of associated passive components.

A first switching stage output 19 is connected to the control line 18 at a point between the two FETs Q1, Q2. A second switching stage output 20 is connected to one of the two support lines 15,16.

By suitable complimentary switching of the FETs Q!, Q2 between conducting and non-conducting states one can switch the switching stage 14 between an open configuration and a closed configuration. In the closed configuration Q2 is in the conducting state and Q1 is in the non-conducting state. The two switching stage outputs 19,20 are therefore closed circuit at DC. In the open configuration Q2 is in the non-conducting state and Q1 is in the conducting state. The switching stage 14 therefore has capacitive input impedance between the two switching stage outputs 19,20.

The switching stage 14 has a breakdown voltage. It is desired that the voltage between the two switching stage outputs 19,20 does not exceed the breakdown voltage at any point during the operation of the switching stage 14.

Shown in figure 3(b) is a further embodiment of a switching stage 14 of a subsea DC to DC voltage converter according to the invention. This embodiment of a switching stage 14 is a full bridge switching stage 14. The full bridge switching stage 14 is similar to the half bridge switching stage 14 except it comprises two control lines 18 extending between the support lines 15,16. Each control line 18 comprises two FETS. The first switching stage output 19 is connected to the first control line 18 between the two FETS of that line. The second switching stage output 20 is connected to the second control line 18 between the two FETs of that line. As with the half bridge switching stage 14, by suitable switching of the FETs the switching stage 14 can be switched between open and closed configurations. Use of a full bridge switching stage 14 is preferred for bi-directional power flow systems.

Shown in figure 4 is a first embodiment of a subsea DC to DC voltage converter 30 according to the invention. The subsea DC to DC voltage converter 30 comprises a DC to AC voltage conversion stage 31 comprising first and second output lines 32,33. The subsea DC to DC voltage converter 30 further comprises an AC to DC voltage conversion stage 34. The AC to DC voltage conversion stage 34 is connected to the first and second output lines 32,33.

The DC to AC voltage conversion stage 31 comprises first and second voltage supply lines 35,36. Extending between the voltage supply lines 35,36 are first and second conversion lines 37,38. The first conversion line 37 comprises a plurality of switching stages 14 connected together in a series chain with the first switching stage output 19 of each switching stage 14 being connected to the second switching stage output 20 of the previous switching stage 14 in the chain. The first switching stage output 19 of the first switching stage 14 in the chain is connected to the first voltage supply line 35. The second switching stage output 20 of the last switching stage 14 in the chain is connected to the second voltage supply line 36. The first output line 32 is connected to the first conversion line 37 part way along the length of the first conversion line 37. In this embodiment, there are an equal number of switching stages 14 on each side of the first output line 32.

The second conversion line 38 comprises a plurality of capacitors 39 connected together in series. The second output line 33 is connected to the second conversion line 38 part way along the second conversion line 38. In this embodiment, there are an equal number of capacitors 39 on each side of the second output line 33.

The subsea DC to DC voltage converter 30 further comprises a controller 40 connected to the switching stages 14. The controller 40 switches the switching stages 14 between open and closed configurations by switching the FETS of the switching stages 14 between conducting and non-conducting states.

In use, a DC voltage Δv is provided between the first and second voltage supply lines 35, 36 which are at V1 and V2 respectively (V1-V2 = ΔV). This is supplied by the ship borne DC power supply 2 via the umbilical cable 5. The capacitors 39 hold the voltage of the second output line 33 constant. In this embodiment, all four capacitors 39 are of the same capacitance and the voltage of the second output line 33 is held half way between the voltages of the first and second voltage supply lines 35,36 ie at (V1 + V2)/2. The controller 40 switches the switching stages 14 between the open and closed configurations to produce a square wave voltage difference between the first and second output lines 32,33. This is achieved by in a first step switching S3 and S4 to the open configuration and S1 and S2 to the closed configuration. The voltage of the first output line 32 is therefore equal to the voltage of the first voltage supply line 35 i.e. V1. The voltage between the switching stage outputs 19,20 for each of S3 and S4 is ΔV/2 which is less than the breakdown voltage of each switching stage 14. The voltage difference between the switching stage outputs 19,20 of each of S1 and S2 is zero. In a second step the configurations of the switching stages 14 are reversed. The voltage of the first output line 32 is therefore equal to the voltage of the second voltage supply line 36 i.e. V1. The two steps are repeated to produce a square wave. A number of different patterns of switching of the FETs of the switching stages 14 are possible. Generally speaking it is preferred that the FETS are switched in a balanced pattern which maintains the voltage across the capacitors 17 in each switching stage 14 at ΔV/2.

The square wave voltage produced by the DC to AC conversion stage 31 is received by the AC to DC conversion stage 34. The AC to DC conversion stage 34 converts the AC voltage (in this case a square wave voltage) to a DC voltage at a plurality of output ports 41. Loads 42 are connected to one or more of the output ports 41. The operation of the AC to DC conversion stage 31 is described in more detail below.

If the voltage difference between the two voltage supply lines 35,36 is ΔV then with this pattern of switching of the switching stages 14 the maximum voltage which appears across the switching stage outputs 19,20 of any one switching stage 14 is ΔV/2. In alternative embodiments of the DC to AC conversion stage 31 the first conversion line 37 comprises a larger number of switching stages 14, although typically still comprises an equal number of switching stages 14 on each side of the first output line 32. If the first conversion line 37 comprises N switching stages 14 on each side of the first output line 32 then, with this switching pattern, the maximum voltage that will appear across the switching stage outputs 19,20 of any one switching stage 14 will be ΔV/N. The DC to AC voltage conversion stage 31 can therefore be used with any power supply 2 provided it comprises a sufficient number of switching stages 14 in the first conversion line 37 to prevent the voltage appearing across any switching stage 14 from exceeding the breakdown voltage of the switching stage 14. In this case the balanced switching pattern maintains a voltage of ΔV/n across each of the capacitors 17 of the switching stages 14.

Other switching patterns are possible. Figure 5 shows an alternative switching pattern which produces a multi-level periodic time varying voltage on the first output line 32. Step 2 and step 4 both produce a voltage on the first output line 32 of V/2 (assuming the voltage supply lines are at V and zero volts respectively) however this is achieved by different configurations of the switching stages 14. This is preferred.

Shown in figure 6 is a further embodiment of a subsea DC to DC voltage converter 30 according to the invention. This embodiment is similar to that of figure 4 except both first and second conversion lines 37,38 comprise a plurality of switching stages 14 connected together in a series chain. The controller 40 controls the switching of all of these switching stages 14 to produce time a varying voltage (typically a square wave) between both first and second output lines 32,33.

Shown in figure 7 is an embodiment of an AC to DC voltage conversion stage 34 of a subsea DC to DC voltage converter 30 according to the invention. The AC to DC voltage conversion stage 34 comprises a step-down transformer 43. The primary coil 44 of the step-down transformer 43 is connected to the first and second output lines 32,33. The step-down transformer 43 comprises a plurality of secondary coils 45. Each secondary coil 45 is connected to a separate voltage conversion module 46. Each voltage conversion module 46 is in turn connected to a load 47. In alternative embodiments of the invention the transformer 43 may be a one to one transformer or step up transformer.

In use, the AC voltage received across the primary coil 44 from the first and second output lines 32,33 is stepped down and appears as an AC voltage across each of the secondary coils 45. Each of these stepped down AC voltages is received by the associated voltage conversion module 46. The voltage conversion module 46 converts this to a stepped down DC voltage and provides it to the attached load 47.

Figure 8 shows a first embodiment of a voltage conversion module 46 of the AC to DC conversion stage 34 along with its associated secondary coil 45. The voltage conversion module 46 comprises a center tapped full wave rectifier 48 which is in turn connected to a low pass filter 49.

Figure 9 shows a further embodiment of a voltage conversion module 46 of the AC to DC conversion stage 34 again with its associated secondary coil 45. The voltage conversion module 46 comprises a center tapped synchronous rectifier 48 and associated low pass filter 49. The choice of rectifier 48 and filter 49 depends on the circuit topology and transformer design.

Figure 10 shows a further embodiment of a voltage conversion module 46 of the AC to DC voltage conversion stage again with its associated secondary coil 45.

Figure 11 shows an embodiment of an AC to DC conversion stage 34 of a subsea DC to DC voltage converter 30 according to the invention. This embodiment shows a bipolar power supply output where a plus/minus output can be achieved. Moreover, this will allow imbalance between the positive and negative outputs. The extra capacitor 50 across the plus and minus outputs adds extra filtering.

All of the embodiments of the AC to DC voltage conversion stage 34 shown in figures 8 to 11 show examples of output rectification and filtering. This performs the AC to DC conversion between the secondary coil 45 and the load 47. Other forms of rectification are possible such as a basic diode rectifier or a synchronous rectifier MOSFET bridge.

In the above embodiments, each switching stage 14 is identical and are all either full bridge switching stages 14 or half bridge switching stages 14. In an alternative embodiment of the invention the DC to AC conversion stage 31 comprises a mixture of full bridge and half bridge switching stages 14.

Typically, some degree of redundancy is built into the subsea DC to DC voltage converter 30 according to the invention. With reference to the embodiment of figure 14, if for example the DC to DC converter 30 is to be used with an 8KV voltage source and the maximum voltage that can be tolerated across an individual switching stage 14 is 800 Volts then ten switching stages are required in the first conversion line 37 on each side of the first output line 32. Typically however a larger number of switching stages 14 are included in the first conversion line 37. In this way if any one switching stage 14 fails the voltage which appears across the remaining switching stages 14 is still within tolerance limits.

The DC to AC voltage conversion stage 31 typically produces an AC voltage in the frequency range 50KHz to 5MHz but is not necessarily so limited. Preferably the frequency is above mains frequency.

CLAIMS

1. A subsea DC to DC voltage converter comprising

a DC to AC voltage conversion stage comprising first and second output lines,

an AC to DC voltage conversion stage connected to the first and second output lines;

the DC to AC voltage conversion stage comprising

first and second voltage supply lines;

first and second conversion lines extending in parallel between the voltage supply lines;

at least one of the conversion lines comprising a plurality of switching stages, each switching stage comprising first and second switching stage outputs, each switching stage being adapted to be switched between an open configuration in which it has a capacitive input impedance between the two switching stage outputs and a closed configuration in which the two switching stage outputs are closed circuit at DC, the switching stages being connected together in a series chain with the first switching stage output of each switching stage being connected to the second switching stage output of the previous switching stage in the chain;

the first output line connected to the first conversion line part way along its length; and,

the second output line connected to the second conversion line part way along its length;

the AC to DC voltage conversion stage comprising

a transformer comprising a primary coil and at least one secondary coil, the primary coil being connected to the first and second output lines, the at least one secondary coil being connected to a voltage conversion module for converting the received time varying voltage to a DC voltage;

the subsea DC to DC voltage converter further comprising a controller connected to the switching stages for switching the switching stages between open and closed configurations to produce a periodic time varying voltage difference between the first and second output lines.

2. A subsea DC to DC voltage converter as claimed in claim 1, wherein each switching stage is a full bridge switching stage or a half bridge switching stage.

3. A subsea DC to DC voltage converter as claimed in claim 2 wherein each switching stage is a full bridge switching stage.

4. A subsea DC to DC voltage converter as claimed in claim 2, wherein each switching stage is a half bridge switching stage.

5. A subsea DC to DC voltage converter as claimed in any one of claims 1 to 4, wherein the controller switches the switching stages in a pattern resulting in a square wave voltage between the first and second output lines.

6. A subsea DC to DC voltage converter as claimed in any one of claims 1 to 5, wherein the controller switches the switching stages such that no switching stage experiences a voltage difference between its first and second switching stage outputs greater than the breakdown voltage of the switching stage.

7. A subsea DC to DC voltage converter as claimed in any one of claims 1 to 6, wherein the voltage conversion module comprises a rectifier connected to the secondary coil.

8. A subsea DC to DC voltage converter as claimed in claim 7, further comprising a low pass filter connected to the output of the rectifier.

9. A subsea DC to DC voltage converter as claimed in any one of claims 1 to 8, wherein the transformer of the AC to DC voltage conversion stage comprises a plurality of secondary coils each having a voltage conversion module connected thereto.

10. A subsea DC to DC voltage converter as claimed in any one of claims 1 to 9, wherein the first conversion line comprises a plurality of switching stages connected together in a series chain, the first output line being arranged such that it has at least one, preferably two switching stages on each side.

11. A subsea DC to DC voltage converter as claimed in claim 10 wherein the first output line has an equal number of switching stages on each side.

12. A subsea DC to DC voltage converter as claimed in either of claims 10 or 11 wherein the second conversion line comprises a plurality of capacitors connected in series, the second output line being connected such that it has at least one capacitor on each side.

13. A subsea DC to DC voltage converter as claimed in either of claims 10 or 11 wherein the second conversion line comprises a plurality of switching stages connected together in a series chain, the second output line being arranged such that it has at least one, preferably two switching stages on each side

14. A subsea DC to DC voltage converter as claimed in claim 13 wherein the second output line has an equal number of switching stages on each side.

15. A subsea DC to DC voltage converter as claimed in claim 13, wherein the first and second conversion lines comprise an equal number of switching stages, the first and second output lines being arranged in identical positions along their respective conversion lines.

16. A subsea DC to Dc voltage converter as claimed in any one of claims 1 to 15, wherein each switching stage comprises a capacitor which provides the capacitive input impendence when the switching stage is in the open configuration, the controller being adapted to switch the switching stages in a balanced pattern such that the voltage across each capacitor remains substantially constant.

17. A subsea DC to DC voltage converter as claimed in any one of claims 1 to 16 further comprising a DC voltage source connected across the first and second voltage supply lines.

18. A subsea DC to DC voltage converter as claimed in claim 17 wherein the voltage source is connected to the first and second voltage lines via an umbilical cord.

Intellectual
Property
Office

Application No: GB1712428.0 **Examiner:** Mr Chris Davidson
Claims searched: 1-18 **Date of search:** 9 February 2018

Patents Act 1977: Search Report under Section 17

Documents considered to be relevant:

Category	Relevant to claims	Identity of document and passage or figure of particular relevance
X	1-18	EP 2458725 A2 (ABB), see Figure 2 and Figures 5a&5b.
X	1-18	CN 104601003 A (UNIV SOUTHEAST), see Figure 3c.
X	1-18	CN 105099206 A (CSR), see Figure 2 and Figure 4.
X	1-18	CN 104917393 A (HEFEI), see Figure 1.

Categories:

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.

Field of Search:

Search of GB, EP, WO & US patent documents classified in the following areas of the UKC^X :

Worldwide search of patent documents classified in the following areas of the IPC

H02M

The following online and other databases have been used in the preparation of this search report

WPI, EPODOC

International Classification:

Subclass	Subgroup	Valid From
H02M	0003/335	01/01/2006
H02M	0007/53	01/01/2006