

(19)



(11)

EP 2 947 675 A1

(12)

EUROPEAN PATENT APPLICATION

(43) Date of publication:
25.11.2015 Bulletin 2015/48

(51) Int Cl.:
H01H 33/04 (2006.01) **H01H 33/59** (2006.01)
H01H 33/666 (2006.01) **H02H 3/00** (2006.01)

(21) Application number: **14275126.2**

(22) Date of filing: **22.05.2014**

(84) Designated Contracting States:
**AL AT BE BG CH CY CZ DE DK EE ES FI FR GB
GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO
PL PT RO RS SE SI SK SM TR**
Designated Extension States:
BA ME

(72) Inventor: **PARASHAR, Rama Shanker
Stafford ST17 0AL (GB)**

(74) Representative: **Potter Clarkson LLP
The Belgrave Centre
Talbot Street
Nottingham, NG1 5GG (GB)**

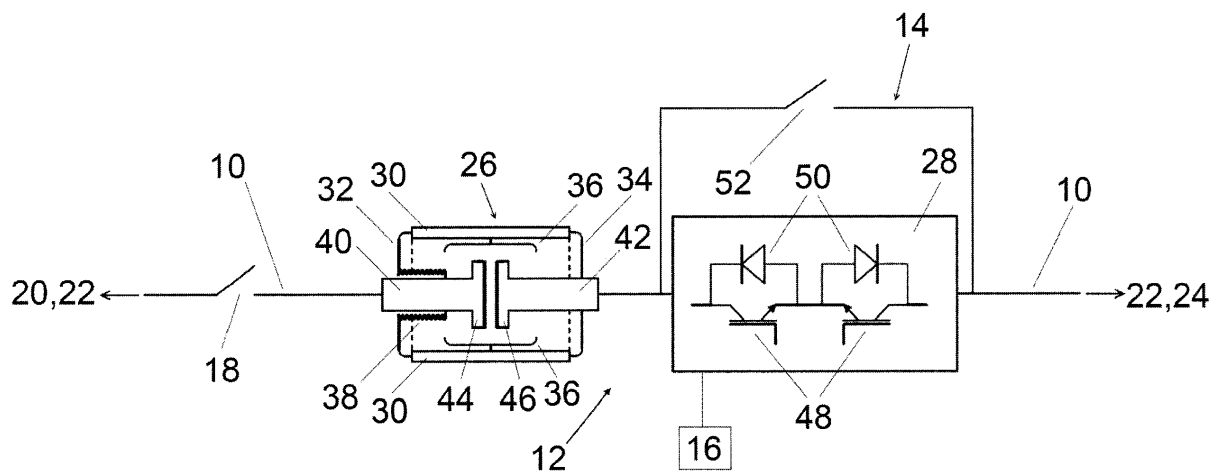
(71) Applicant: **ALSTOM Technology Ltd
5400 Baden (CH)**

(54) Generator power switching apparatus

(57) There is provided a generator power switching apparatus for switching an AC current. The generator power switching apparatus comprises a first switching assembly (12) connected between first and second terminals (10), each terminal (10) being connectable to an electrical network (22), the first switching assembly (12) including:

a vacuum interrupter assembly including at least one vacuum interrupter (26);
an electrical device (28) coupled with the vacuum interrupter assembly; and
a control unit (16) configured to control the electrical device (28) to create a voltage that increases a voltage drop

across the first switching assembly (12), wherein the generator power switching apparatus further includes a current flow path (14) connected between the first and second terminals (10), the current flow path (14) including a mechanical switch (52) operable to selectively open and close the current flow path (14), the current flow path (14) when closed permitting at least part of a current flowing between the first and second terminals (10) to flow through the current flow path (14) and thereby bypass the electrical device (28), the current flow path (14) when opened inhibiting a current flowing between the first and second terminals (10) from flowing through the current flow path (14).

**Figure 1a****EP 2 947 675 A1**

Description

[0001] This invention relates to a generator power switching apparatus for switching an AC current.

[0002] Vacuum interrupters are typically used to act as a load break switch or a circuit breaker in network applications. More particularly, vacuum interrupters are used to interrupt a current flowing in an associated electrical circuit.

[0003] According to an aspect of the invention, there is provided a generator power switching apparatus for switching an AC current, the generator power switching apparatus comprising a first switching assembly connected between first and second terminals, each terminal being connectable to an electrical network, the first switching assembly including:

a vacuum interrupter assembly including at least one vacuum interrupter;
 an electrical device coupled with the vacuum interrupter assembly; and
 a control unit configured to control the electrical device to create a voltage that increases a voltage drop across the first switching assembly,
 wherein the generator power switching apparatus further includes a current flow path connected between the first and second terminals, the current flow path including a mechanical switch operable to selectively open and close the current flow path, the current flow path when closed permitting at least part of a current flowing between the first and second terminals to flow through the current flow path and thereby bypass the electrical device, the current flow path when opened inhibiting a current flowing between the first and second terminals from flowing through the current flow path.

[0004] The or each vacuum interrupter may include a pair of contact electrodes, the contact electrodes being connectable to an electrical network. At least one contact electrode may be movable relative to the other contact electrode to open or close a gap between the contact electrodes.

[0005] During normal operation of the connected electrical network, the mechanical switch is operated to close the current flow path so that at least part of the current flowing between the first and second terminals flows through the current flow path while bypassing the electrical device. Depending on the arrangement of the current flow path and the or each vacuum interrupter, at least part of a current flowing between the first and second terminals may also flow through the or each vacuum interrupter (i.e. through the closed electrodes of the or each vacuum interrupter) at the same time. Closing the current flow path to enable at least part of the current flowing between the first and second terminals to bypass the electrical device reduces heat dissipation from components of the electrical device and thereby reduce thermal

losses in the generator power switching apparatus.

[0006] Optionally an electrical resistance of the mechanical switch may be rated so that the current flow path when closed permits at least part of a current flowing between the first and second terminals to flow through the current flow path and thereby minimise a flow of current through the electrical device. Further optionally the electrical device may be configured to inhibit a current flowing between the first and second terminals from flowing through the electrical device when the current flow path is closed. Configuring the current flow path and/or electrical device in this manner further reduces heat dissipation from components of the electrical device and thereby further reduces thermal losses in the generator power switching apparatus.

[0007] In the event of a need to interrupt the current flowing through the generator power switching apparatus, the contact electrodes of the or each vacuum interrupter are opened to form a gap therebetween. This leads to the formation of an arc in the gap between the contact electrodes of the or each vacuum interrupter.

[0008] An increase in the gap between the contact electrodes of the or each vacuum interrupter initially causes a rise in arc voltage. Once the gap between the contact electrodes is sufficiently large to permit effective distribution of a magnetic field formed between the contact electrodes, the arc voltage stabilises and remains in a certain voltage level or range, e.g. 30-120V. The or each vacuum interrupter then interrupts the current, thus leading to full dielectric recovery of the or each vacuum interrupter at a natural current zero. Such a natural current zero may, for example, be present during operation of a 50/60Hz power circuit.

[0009] The mechanical switch may be configured to open the current flow path prior to operation of the vacuum interrupter assembly to interrupt a current flowing between the first and second terminals. Configuring the mechanical switch in this manner ensures that none of the current flowing between the first and second terminals bypasses the electrical device, thereby allowing the current flowing between the first and second terminals to continue flowing through the first switching assembly even when the current flow path is opened.

[0010] In embodiments in which at least one contact electrode is movable relative to the other contact electrode to open or close a gap between the contact electrodes, the control unit may be configured to control the electrical device to create a voltage on or after formation of a gap between the contact electrodes of the or each vacuum interrupter.

[0011] The inclusion of the electrical device in the generator power switching apparatus according to the invention enables the creation of a voltage for combination with the arc voltage between the contact electrodes of the or each vacuum interrupter so as to increase the voltage drop across the first switching assembly. The provision of the increased voltage drop across the first switching assembly helps to rapidly reduce a DC component

and any AC asymmetry present in the electrical network connected to the first and second terminals. As a result, the arcing time across the contact electrodes of the or each vacuum interrupter is considerably reduced, thus lowering thermal and mechanical stress in the or each vacuum interrupter. In addition, the provision of the increased voltage drop across the first switching assembly means that, subsequent to current interruption, the rate of rise of recovery voltage (RRRV) is damped and the transient recovery voltage is shared between the vacuum interrupter assembly and the electrical device, thus reducing dielectric stress in the or each vacuum interrupter.

[0012] Moreover, the reduction in arcing time across the contact electrodes of the vacuum interrupter compensates for the time taken to operate the mechanical switch to open the current flow path.

[0013] The electrical device may be configured to inhibit a current flowing between the first and second terminals from flowing through the electrical device upon formation of a predefined magnitude of current in the vacuum interrupter assembly. Configuring the electrical device in this manner helps the vacuum interrupter assembly to interrupt the current flowing between the first and second terminals and thereby further reduces the arcing time across the contact electrodes of the or each vacuum interrupter.

[0014] In view of the foregoing the combination of the current flow path and electrical device in the generator power switching apparatus improves the efficiency and reliability of the generator power switching apparatus during its operation to conduct a current in a normal operating mode and to interrupt a current in a current interruption mode.

[0015] The magnitude of the voltage created by the electrical device may vary depending on the current interruption requirements of the vacuum interrupter assembly. For example, the electrical device may be configured to create a voltage that is at least one or two orders of magnitude higher than an arc voltage generated by the vacuum interrupter assembly, and/or the electrical device may be configured to be controllable to create a voltage in the range of 1-5 kV or in the range of 5-10 kV.

[0016] In further embodiments of the invention, the electrical device may be a voltage generator or gas filled switch.

[0017] The voltage generator may include at least one semiconductor switching device or a plurality of series-connected semiconductor switching devices. This allows the electrical device to present a low impedance based on closed semiconductor switching devices when current flows through the electrical device.

[0018] The electrical device may be connected in series with the vacuum interrupter assembly. This allows a voltage created by the electrical device to be combined in series with the arc voltage across the vacuum interrupter assembly so as to increase the total voltage across the first switching assembly.

[0019] The current flow path may be connected be-

tween the first and second terminals in various ways in order to enable it to carry out its function. In embodiments of the invention, the current flow path may be further connected in parallel with the electrical device. In other embodiments of the invention, the current flow path may be connected in parallel with the first switching assembly.

[0020] The number and arrangement of vacuum interrupters in the vacuum interrupter assembly may vary depending on the design requirements of the generator power switching apparatus. The vacuum interrupter assembly may, for example, include a plurality of series-connected and/or parallel-connected vacuum interrupters.

[0021] Multiple vacuum interrupters may be connected to define different configurations of the vacuum interrupter assembly in order to vary its operating voltage and current characteristics to match the requirements of the associated power application.

[0022] In still further embodiments of the invention, the generator power switching apparatus may further include a second switching assembly connected in parallel with the first switching assembly between the first and second terminals. The second switching assembly may include at least one pulsed power switch. The or each pulsed power switch may be configured to be operable to modify a current flowing through the first switching assembly. The pulsed power switch is simple in design with no moving parts, and can be designed to handle bidirectional power flow. In addition, the pulsed power switch is capable of switching off power flow after a predetermined period of conduction, and has rapid switching capability, e.g. the period taken to switch from a closed state to an open state can vary in the range of nanoseconds to a few milliseconds. The pulsed power switch can support a high voltage drop in its open state, e.g. up to a few MV, can dissipate energy at a rate of up to 10^9 - 10^{12} Joules per second, and is capable of carrying out repetitive operation. This in turn renders the pulsed power switch compatible for use in the second switching assembly to aid current interruption in high voltage applications.

[0023] The or each pulsed power switch may be, for example, any one of:

- a pulsed power switch of the hard tube type, e.g. a triode, a tetrode;
- a pulsed power switch of the plasma tube type, e.g. a magnetically-quenched thyatron, a crossed-field plasma discharge switch or a crossatron, a hollow-cathode discharge-based hollotron;
- a plasma erosion switch;
- a reflex triode switch.

[0024] Examples of pulsed power switches and their operation are described in:

- K. H. Schoenbach, A review of opening switch technology for inductive energy storage, proceedings of The IEEE, Vol. 72, No. 8, pp. 1019-1040, August

1984

- K.H. Schoenbach, M. Kristiansen, Diffuse Discharges and Opening Switches - A Review of the Tamarow Workshops, Proceeding of 4th IEEE Pulsed Power conference, Albuquerque, New Mexico, pp. 26-32, 1983
- K. H. Schoenbach, M. Kristiansen, G. Schaefer, A review of opening switch technology for inductive energy storage, Proceedings of the IEEE, Vol. 72, No. 8, pp.1019 - 1040, August 1984

[0025] Pulsed power switches of the hard tube type are high vacuum devices with a hot-cathode filament based cathode, and require a high forward voltage to achieve conduction.

[0026] Pulsed power switches of the plasma tube type are gas-filled devices, and require a relatively lower forward voltage to achieve conduction. The nature of the filled gas may be, but is not limited to, hydrogen, nitrogen, argon, neon, xenon, or other gases and gas mixtures. Depending upon the design of the pulsed power switch, gases or gas mixtures are selected to provide the lowest forward voltage to reduce heat dissipation during normal conduction and to withstand high voltage during non-conduction. Gases such as helium, krypton or hydrogen provide enhanced switching characteristics.

[0027] As mentioned earlier, an increase in the gap between the contact electrodes of the or each vacuum interrupter initially causes a rise in arc voltage. Once the gap between the contact electrodes is sufficiently large to permit effective distribution of a magnetic field between the contact electrodes, the arc voltage stabilises and remains in a certain voltage level or range, e.g. 30-120V. Meanwhile the electrical device creates a voltage for combination with the arc voltage between the contact electrodes of the or each vacuum interrupter so as to increase the voltage drop across the first switching assembly. At this stage switching the second switching assembly to a closed state transfers a current from the first switching assembly to the second switching assembly. This, together with the rise in voltage drop across the first switching assembly, allows the current in the or each vacuum interrupter to drop rapidly to zero, and thereby allow full dielectric recovery of the or each vacuum interrupter. This is followed by the second switching assembly being controlled to switch back to an open state to complete the current interruption process.

[0028] The second switching assembly therefore provides additional control over the current interruption process by enabling modification of the magnitude of current flowing through the vacuum interrupter assembly during the current interruption process. Furthermore the second switching assembly can be switched to modify the magnitude of current flowing in the or each vacuum interrupter during the current interruption process to minimise any adverse effects of high current densities on the contact electrodes to thereby improve the lifetime of the vacuum interrupter assembly.

[0029] The parallel connection of the first and second switching assemblies in the generator power switching apparatus therefore improves the current interruption process. In addition, the parallel connection of the first and second switching assemblies in the generator power switching apparatus results in a simple layout of the generator power switching apparatus, which in turn reduces the manufacturing and installation costs of such an apparatus.

[0030] As with the vacuum interrupter assembly, multiple pulsed power switches may be connected to define different configurations of the second switching assembly in order to vary its operating voltage and current characteristics to match the requirements of the associated power application. The second switching assembly may, for example, include a plurality of series-connected and/or parallel-connected pulsed power switches. Furthermore, the electrical device may be configured to create a voltage that increases a voltage drop across the first switching assembly so as to reduce an arc current in the or each vacuum interrupter and thereby cause formation of an unstable arc in the or each vacuum interrupter. This in turn leads to dielectric recovery of the or each vacuum interrupter. In this manner it is possible to obtain a low arcing time across the contact electrodes of the or each vacuum interrupter, and achieve successful current interruption without requiring a current zero. A generator power switching apparatus with an electrical device configured as such may be suitable for use with an AC electrical network carrying a current with a high DC component.

[0031] Examples of applications that are compatible with the generator power switching apparatus according to the invention include, for example, AC power networks, AC high voltage circuit breakers, AC generator circuit breakers, transmission lines, railway traction, ships, superconducting magnetic storage devices, high energy fusion reactor experiments, stationary power applications, renewable energy resources such as fuel cells and photovoltaic cells.

[0032] Preferred embodiments of the invention will now be described, by way of non-limiting examples, with reference to the accompanying drawings in which:

Figure 1a shows, in schematic form, a generator power switching apparatus according to a first embodiment of the invention;

Figure 1b shows, in schematic form, a generator power switching apparatus according to a second embodiment of the invention;

Figure 2 shows, in schematic form, a generator power switching apparatus according to a third embodiment of the invention; and

Figure 3 shows, in schematic form, a generator power switching apparatus according to a fourth embodiment of the invention.

[0033] A first generator power switching apparatus ac-

cording to a first embodiment of the invention is shown in Figure 1a.

[0034] The first generator power switching apparatus comprises first and second terminals 10, a first switching assembly 12, a current flow path 14, and a control unit 16.

[0035] In use, one of the terminals 10 of the first generator power switching apparatus is connected via an isolator 18 to a first terminal 20 of an AC electrical circuit 22, and the other of the terminals 10 of the first generator power switching apparatus is connected to a second terminal 24 of the AC electrical circuit 22.

[0036] The first switching assembly 12 includes a vacuum interrupter assembly. The vacuum interrupter assembly includes a single vacuum interrupter 26. The first switching assembly 12 further includes a voltage generator 28.

[0037] In other embodiments of the invention, the vacuum interrupter assembly may include a plurality of vacuum interrupters.

[0038] The vacuum interrupter includes a cylindrical housing 30, a first end flange 32 and a second end flange 34 assembled to define a vacuum tight enclosure. Each end flange 32,34 is brazed to the cylindrical housing 30 to form a hermetic joint. The vacuum interrupter 26 further includes a centre shield 36 that overlaps inner walls of the cylindrical housing 30 to protect the inner walls of the cylindrical housing 30 from metal vapour deposition arising from arc discharge.

[0039] Each cylindrical housing 30 is metallised and nickel-plated at both ends. The length and diameter of the respective cylindrical housing 30 varies depending on the operating voltage rating of the vacuum interrupter 26, while the dimensions and shape of the first and second end flanges 32,34 may vary to correspond to the size and shape of the cylindrical housing 30.

[0040] The vacuum interrupter 26 also includes a tubular bellows 38 and first and second electrically conductive rods 40,42.

[0041] The first end flange 32 includes a hollow bore dimensioned to accommodate the tubular bellows 38, while the second end flange 34 includes a hollow bore dimensioned to accommodate the second rod 42 within its hollow bore. The tubular bellows 38 also includes a hollow bore for retention of the first rod 40.

[0042] The first and second rods 40,42 are respectively retained within the hollow bores of the tubular bellows 38 and the second end flange 34 so that the second ends of the rods 40,42 are located inside the enclosure and the first ends of the rods 40,42 are located outside the enclosure. The first and second rods 40,42 may be fabricated from, for example, oxygen-free high conductivity (OFHC) copper.

[0043] The vacuum interrupter 26 further includes first and second contact electrodes 44,46 which are in the form of arc control electrodes that are suitably shaped to generate an axial magnetic field in a gap between the first and second contact electrodes 44,46.

[0044] The first contact electrode 44 is mounted at the

second end of the first rod 40, while the second contact electrode 46 is mounted at the second end of the second rod 42. The rods 40,42 are coaxially aligned so that the first and second contact electrodes 44,46 define opposed electrodes.

[0045] Each contact electrode 44,46 is made from a refractory material, which may be selected from a group of, for example, copper-chromium, copper-tungsten, copper tungsten carbide, tungsten, chromium or molybdenum. These refractory materials not only exhibit excellent electrical conductivity, but also display high dielectric strength subsequent to the current interruption.

[0046] Corrugated walls of the tubular bellows 38 allow the tubular bellows 38 to undergo expansion or contraction so as to increase or decrease the tubular length of the tubular bellows 38. This allows the first rod 40 to move relative to the second rod 42 between a first position where the first and second contact electrodes 44,46 are kept in contact, and a second position where the first and second contact electrodes 44,46 are kept at a maximum separation therebetween. The second rod 42 is kept at a fixed position.

[0047] The voltage generator 28 includes a plurality of series-connected semiconductor switching devices. Each semiconductor switching device constitutes an insulated gate bipolar transistor 48 connected in parallel with an anti-parallel diode 50. It is envisaged that, in other embodiments of the invention, each insulated gate bipolar transistor may be replaced by a different type of semiconductor switching device, and/or the plurality of series-connected semiconductor switching devices may be replaced by a single semiconductor switching device.

[0048] In use, the vacuum interrupter 26 is connected in series with the voltage generator 28 between the terminals 10 of the first generator power switching apparatus so that the first end of the first rod 40 is connected via the isolator 18 to the first terminal 20 of the AC electrical circuit 22, the first end of the second rod 42 is connected in series with the voltage generator 28, and the voltage generator 28 is connected to the second terminal 24 of the AC electrical circuit 22.

[0049] The current flow path 14 is further connected in parallel with the voltage generator 28. The current flow path 14 includes a mechanical switch 52 operable to selectively open and close the current flow path 14. The current flow path 14 when closed permits at least part of a current flowing between the first and second terminals 10 of the first generator power switching apparatus to flow through the current flow path 14 and thereby bypass the voltage generator 28. The current flow path 14 when opened inhibits a current flowing between the first and second terminals 10 of the first generator power switching apparatus from flowing through the current flow path 14.

[0050] In use, the control unit 16 controls the voltage generator 28 to selectively generate a voltage, and switches the semiconductor switching devices to either enable the voltage generator 28 to insert the generated

voltage in series with the vacuum interrupter 26, or provide a low impedance path for the current flowing through the first switching assembly 12.

[0051] During normal operation of the connected AC electrical circuit 22, the tubular bellows 38 is controlled to move the first rod 40 to the first position to bring the first and second contact electrodes 44,46 into contact. Meanwhile the mechanical switch 52 is operated to close the current flow path 14, and the semiconductor switching devices of the voltage generator 28 are switched off to inhibit a current flowing between the first and second terminals 10 of the first generator power switching apparatus from flowing through the voltage generator 28 when the current flow path is closed. This allows current to flow between the second and first terminals 24,20 of the connected AC electrical circuit 22 via the electrically conductive rods 40,42 of the vacuum interrupter 26 and via the current flow path 14 while bypassing the voltage generator 28.

[0052] Closing the current flow path 14 to enable the current flowing between the first and second terminals 10 of the first generator power switching apparatus to bypass the voltage generator 28, and switching off the semiconductor switching devices of the voltage generator 28 to inhibit the current flowing between the first and second terminals 10 of the first generator power switching apparatus from flowing through the voltage generator 28, reduces heat dissipation from the semiconductor switching devices of the voltage generator 28 and thereby reduce thermal losses in the first generator power switching apparatus.

[0053] It is envisaged that, during normal operation of the connected AC electrical circuit 22, the semiconductor switching devices of the voltage generator 28 may instead be switched on (instead of being switched off) to allow at least part of a current flowing between the first and second terminals 10 of the first generator power switching apparatus to flow through the voltage generator 28 when the current flow path 14 is closed.

[0054] In the event of a fault resulting in a high fault current flowing in the connected AC electrical circuit, the current must be interrupted in order to prevent the high fault current from damaging components of the AC electrical circuit 22. Interruption of the fault current permits isolation and subsequent repair of the fault in order to restore the AC electrical circuit 22 to normal operating conditions.

[0055] The current interruption process is initiated by the control unit 16 switching the semiconductor switching devices to provide the low impedance path for the current flowing between the first and second terminals 10 of the first generator power switching apparatus. This is followed by operation of the mechanical switch 52 to open the current flow path 14 and thereby cause current to commutate from the current flow path 14 to the voltage generator 28. This ensures that none of the current flowing between the first and second terminals 10 of the first generator power switching apparatus bypasses the volt-

age generator 28, thereby allowing the current flowing between the first and second terminals 10 of the first generator power switching apparatus to continue flowing through the first switching assembly 12 even when the current flow path 14 is opened.

[0056] The current interruption process is continued by controlling the tubular bellows 38 to move the first rod 40 towards its second position so as to separate the first and second contact electrodes 44,46. The separation of the first and second contact electrodes 44,46 results in the formation of a gap between the first and second contact electrodes 44,46, which leads to the formation of an arc in this gap.

[0057] The arc consists of metal vapour plasma, which continues to conduct the current flowing between the first and second contact electrodes 44,46. This is because the metal vapour plasma remains electrically charged under an electric field generated between the two electrodes 44,46. Charged plasma ions travel between the first contact electrode 44 and the second contact electrode 46, and so the flow of current remains established between the two contact electrodes 44,46.

[0058] An increase in the gap between the contact electrodes 44,46 of the vacuum interrupter 26 initially causes a rise in arc voltage between the contact electrodes 44,46. When the first rod 40 reaches its second position, i.e. the contact electrodes 44,46 are at their maximum separation, the maximum arc voltage (e.g. 30-120 V) of the vacuum interrupter 26 is established. At this stage the gap between the contact electrodes 44,46 is sufficiently large to permit effective distribution of the axial magnetic field between the contact electrodes 44,46 and thereby allow the arc voltage to stabilise.

[0059] On or after formation of a gap between the contact electrodes 44,46 of the vacuum interrupter 26, the control unit 16 controls the voltage generator 28 to generate a voltage (e.g. 1-5kV) and switches the semiconductor switching devices to enable the voltage generator 28 to insert the generated voltage in series with the vacuum interrupter 26. The series combination of the maximum arc voltage of the vacuum interrupter 26 and the voltage created by the voltage generator 28 causes a rise in voltage drop across the first switching assembly 12.

[0060] The provision of the increased voltage drop across the first switching assembly 12 helps to rapidly reduce a DC component and AC asymmetry present in the AC electrical circuit. This allows the arc current in the vacuum interrupter 26 to drop to a lower current value and thereby reduces the time required to attain a current zero, and as a result the arcing time across the contact electrodes 44,46 of the vacuum interrupter 26 is considerably reduced, thus lowering thermal and mechanical stress in the vacuum interrupter 26. Current interruption occurs at the natural current zero. At this stage the isolator 18 can be opened. Subsequent to current interruption, the rate of rise of recovery voltage (RRRV) is damped and the transient recovery voltage is shared be-

tween the vacuum interrupter 26 and the voltage generator 28, thus reducing dielectric stress in the vacuum interrupter 26.

[0061] Moreover, the reduction in arcing time across the contact electrodes 44,46 of the vacuum interrupter 26 compensates for the time taken to operate the mechanical switch 52 to open the current flow path 14.

[0062] The duration of current interruption is limited by the time required to mechanically move the first rod 40 from the first position to the second position, which could be 1 to 40 ms and would depend on the opening speed of the first rod 40, and the time to operate the voltage generator 28, which is typically 1 ms.

[0063] In view of the foregoing the combination of the current flow path 14 and voltage generator 28 in the first generator power switching apparatus improves the efficiency and reliability of the first generator power switching apparatus during its operation to conduct a current in a normal operating mode and to interrupt a current in a current interruption mode.

[0064] It will be appreciated that the first generator power switching apparatus may be operated, for example, as a generator circuit breaker for a power generator rated at 100 MVA or less.

[0065] A second generator power switching apparatus according to a second embodiment of the invention is shown in Figure 1 b. The second generator power switching apparatus of Figure 1b is similar in structure and operation to the first generator power switching apparatus of Figure 1a, and like features share the same reference numerals.

[0066] The second generator power switching apparatus differs from the first generator power switching apparatus in that, in the second generator power switching apparatus, the voltage generator 28 is replaced by a gas filled switch 54.

[0067] The gas filled switch 54 is filled with gas at high pressure in the range of 10 to 100 bar. In the embodiment shown, the gas is hydrogen. It is envisaged that the gas in the gas filled switch 54 may be argon, nitrogen, a hydrogen-argon mixture or a hydrogen-nitrogen mixture.

[0068] The structure and operation of the gas filled switch 54 is similar to that of the vacuum interrupter 26. In use, the control unit 16 controls the gas filled switch 54 by moving its first rod 56 relative to its second rod 58 to open or close a gap between its contact electrodes 60. When a gap is formed between the contact electrodes 60 of the gas filled switch 54, an arc voltage is created between the opened contact electrodes 60 and thereby inserted in series with the vacuum interrupter 26, by virtue of the series connection of the vacuum interrupter 26 and gas filled switch 54.

[0069] Once the current interruption process is initiated and on or after formation of a gap between the contact electrodes 44,46 of the vacuum interrupter 26, the control unit 16 controls the gas filled switch 54 to create an arc voltage in the gas filled switch 54, and so the arc voltage of the gas filled switch 54 is inserted in series with the

arc voltage of the vacuum interrupter 26. The series combination of the arc voltages of the vacuum interrupter 26 and gas filled switch 54 causes a rise in voltage drop across the first switching assembly 12.

[0070] It will be appreciated that the second generator power switching apparatus may be operated, for example, as a generator circuit breaker for a power generator rated at 100 MVA or less.

[0071] A third generator power switching apparatus according to a third embodiment of the invention is shown in Figure 2. The third generator power switching apparatus of Figure 2 is similar in structure and operation to the first generator power switching apparatus of Figure 1a, and like features share the same reference numerals.

[0072] The third generator power switching apparatus differs from the first generator power switching apparatus in that, in the third generator power switching apparatus, the current flow path is connected in parallel with the first switching assembly 12, instead of just the voltage generator 28.

[0073] During normal operation of the connected AC electrical circuit 22, the tubular bellows 38 is controlled to move the first rod 40 to the first position to bring the first and second contact electrodes 44,46 into contact. Meanwhile the mechanical switch 52 is operated to close the current flow path 14, and the semiconductor switching devices of the voltage generator 28 are switched on. This allows a current to flow between the second and first terminals 24,20 of the connected AC electrical circuit 22 via the current flow path 14 while bypassing the vacuum interrupter 26 and the voltage generator 28. An electrical resistance of the mechanical switch 52 is rated so that the current flow path 14 when closed permits at least part of a current flowing between the first and second terminals 10 of the third generator power switching apparatus to flow through the current flow path 14 and thereby minimise a flow of current through the first switching assembly 12 (i.e. through the vacuum interrupter 26 and the voltage generator 28).

[0074] Closing the current flow path 14 to enable the bulk of the current flowing between the first and second terminals 10 of the third generator power switching apparatus to bypass the vacuum interrupter 26 and the voltage generator 28 further reduces heat dissipation from the vacuum interrupter 26 and the semiconductor switching devices of the voltage generator 28 and thereby reduce thermal losses in the third generator power switching apparatus.

[0075] The current interruption process for the third generator power switching apparatus is identical to the current interruption process for the first generator power switching apparatus, except that the current interruption process for the third generator power switching apparatus is initiated by operation of the mechanical switch 52 to open the current flow path 14 and thereby cause current to commutate from the current flow path 14 to the first switching assembly 12. This ensures that all of the current flowing between the first and second terminals

10 of the third generator power switching apparatus continues flowing through the first switching assembly 12 even when the current flow path 14 is opened.

[0076] It is envisaged that, during normal operation of the connected AC electrical circuit, the semiconductor switching devices of the voltage generator 28 may be switched off to inhibit a current flowing between the first and second terminals 10 of the third generator power switching apparatus from flowing through the voltage generator 28 when the current flow path 14 is closed, so as to further reduce thermal losses in the third generator power switching apparatus.

[0077] It will be appreciated that the third generator power switching apparatus may be operated, for example, as a generator circuit breaker for a power generator rated at 100 MVA or more.

[0078] A fourth generator power switching apparatus according to a fourth embodiment of the invention is shown in Figure 3. The fourth generator power switching apparatus of Figure 3 is similar in structure and operation to the third generator power switching apparatus of Figure 2, and like features share the same reference numerals.

[0079] The fourth generator power switching apparatus differs from the third generator power switching apparatus in that the fourth generator power switching apparatus further includes a second switching assembly 62.

[0080] The second switching assembly 62 is connected in parallel with the first switching assembly 12 between the first and second terminals 10 of the fourth generator power switching apparatus.

[0081] The second switching assembly 62 includes a single bidirectional pulsed power switch 64. The pulsed power switch 64 includes an anode 66 and a cathode 68. It will be appreciated that the anode 66 and cathode 68 may be respectively connected to the first and second terminals 10 or vice versa. The control unit 16 is configured to selectively send a control signal 70 to switch the pulsed power switch 64 to a closed state.

[0082] The pulsed power switch 64 is simple in design with no moving parts, and can be designed to handle bidirectional power flow. In addition, the pulsed power switch 64 is capable of switching off power flow after a predetermined period of conduction, and has rapid switching capability, e.g. the period taken to switch from a closed state to an open state can vary in the range of nanoseconds to a few milliseconds. The pulsed power switch 64 can support a high voltage drop in its open state, e.g. up to a few MV, can dissipate energy at a rate of up to 10^9 - 10^{12} Joules per second, and is capable of carrying out repetitive operation. This in turn renders the pulsed power switch 64 compatible for use in the second switching assembly 62 to aid current interruption in high voltage applications.

[0083] The current interruption process for the fourth generator power switching apparatus is identical to the current interruption process for the third generator power switching apparatus except that, in the current interrup-

tion process for the fourth generator power switching apparatus:

- the pulsed power switch 64 remains in an open state. This allows current to flow between the second and first terminals 24,20 of the connected AC electrical circuit 22 via the current flow path 14 while bypassing the vacuum interrupter 26, the voltage generator 28, and no current flows through the second switching assembly 62;
- upon control of the voltage generator 28 to insert a voltage (e.g. 1-5 kV) in series with the arc voltage of the vacuum interrupter 26 so as to cause a rise in voltage drop across the first switching assembly 12, the control unit 16 sends the control signal 70 to the pulsed power switch 64 to switch to its closed state.

[0084] At this stage switching the pulsed power switch 64 to switch to its closed state transfers a current from the first switching assembly 12 to the second switching assembly 62. This, together with the rise in voltage drop across the first switching assembly 12, allows the current in the vacuum interrupter 26 to drop rapidly to zero and thereby allows full dielectric recovery of the vacuum interrupter 26. This is followed by the pulsed power switch 64 being switched back to an open state to complete the current interruption process. At this stage the isolator 18 can be opened.

[0085] The duration of the conduction of the pulsed power switch 64 has to be longer than the time needed for the vacuum interrupter 26 to achieve full dielectric recovery, which is typically in the range of 10 μ s.

[0086] The second switching assembly 62 therefore provides additional control over the current interruption process by enabling modification of the magnitude of current flowing through the vacuum interrupter assembly during the current interruption process. Furthermore the second switching assembly 62 can be switched to modify the magnitude of current flowing in the vacuum interrupter 26 during the current interruption process to minimise any adverse effects of high current densities on the contact electrodes 44,46 to thereby improve the lifetime of the vacuum interrupter assembly.

[0087] The parallel connection of the first and second switching assemblies 12, 14 in the fourth generator power switching apparatus therefore improves the current interruption process. In addition, the parallel connection of the first and second switching assemblies 12,14 in the fourth generator power switching apparatus results in a simple layout of the fourth generator power switching apparatus, which in turn reduces the manufacturing and installation costs of such an apparatus.

[0088] Optionally the voltage generator 28 may be configured to inhibit a current flowing between the first and second terminals 10 of the fourth generator power switching apparatus from flowing through the voltage generator 28 in the vacuum interrupter 26 upon formation of a pre-defined magnitude of current in the vacuum interrupter

assembly. Configuring the voltage generator 28 in this manner helps the vacuum interrupter 26 to interrupt the current flowing between the first and second terminals 10 of the fourth generator power switching apparatus and thereby further reduces the arcing time across the contact electrodes 44,46 of the vacuum interrupter 26.

[0089] Further optionally the voltage generator 28 may be configured to create a voltage (e.g. 5-10 kV) that increases a voltage drop across the first switching assembly 12 to a sufficiently high level so that, when the pulsed power switch 64 is switched to its closed state in order to transfer the current from the first switching assembly 12 to the second switching assembly, the arc current in the vacuum interrupter 26 is reduced to a current value that is low enough to result in an unstable arc in the vacuum interrupter 26, thus leading to dielectric recovery of the vacuum interrupter 26. This is followed by the pulsed power switch 64 being switched back to an open state to complete the current interruption process. At this stage the isolator 18 can be opened. In this manner it is possible to obtain a low arcing time across the contact electrodes 44,46 of the vacuum interrupter 26, and achieve successful current interruption without requiring a current zero. As such the fourth generator power switching apparatus may be suitable for use with an AC electrical circuit carrying a current with a high DC component.

[0090] It will be appreciated that the fourth generator power switching apparatus may be operated, for example, as a generator circuit breaker for a power generator rated at 100 MVA or more.

[0091] It is envisaged that, in other embodiments of the invention, each of the first, second and third generator power switching apparatus may include the second switching assembly, whereby the second switching assembly is connected in parallel with the first switching assembly.

[0092] In other embodiments, it is envisaged that the vacuum interrupter assembly may include a plurality of series-connected and/or parallel-connected vacuum interrupters.

[0093] Multiple vacuum interrupters may be connected to define different configurations of the vacuum interrupter assembly in order to improve its operating voltage and current characteristics. For example, connecting multiple vacuum interrupters in series increases the dielectric strength of the vacuum interrupter assembly and thereby permits the use of the vacuum interrupter assembly at higher operating voltages, while connecting multiple vacuum interrupters in parallel permits the vacuum interrupter assembly to interrupt higher levels of current.

[0094] It is envisaged that, in other embodiments of the invention, the second switching assembly may include a plurality of series-connected and/or parallel-connected pulsed power switches.

[0095] As with the vacuum interrupter assembly, multiple pulsed power switches may be connected to define different configurations of the second switching assembly in order to vary its operating voltage and current char-

acteristics to match the power requirements of the associated power application.

[0096] The generator power switching apparatus of Figures 1a, 1b, 2 and 3 are compatible for use, but are not limited to, applications such as AC power networks, AC high voltage circuit breakers, AC generator circuit breakers, transmission lines, railway traction, ships, superconducting magnetic storage devices, high energy fusion reactor experiments, stationary power applications, renewable energy resources such as fuel cells and photovoltaic cells.

Claims

1. A generator power switching apparatus for switching an AC current, the generator power switching apparatus comprising a first switching assembly connected between first and second terminals, each terminal being connectable to an electrical network, the first switching assembly including:

a vacuum interrupter assembly including at least one vacuum interrupter;

an electrical device coupled with the vacuum interrupter assembly; and

a control unit configured to control the electrical device to create a voltage that increases a voltage drop across the first switching assembly, wherein the generator power switching apparatus further includes a current flow path connected between the first and second terminals, the current flow path including a mechanical switch operable to selectively open and close the current flow path, the current flow path when closed permitting at least part of a current flowing between the first and second terminals to flow through the current flow path and thereby bypass the electrical device, the current flow path when opened inhibiting a current flowing between the first and second terminals from flowing through the current flow path.

2. A generator power switching apparatus according to any preceding claim wherein the or each vacuum interrupter includes a pair of contact electrodes, the contact electrodes being connectable to an AC electrical network.

3. A generator power switching apparatus according to Claim 2 wherein at least one contact electrode is movable relative to the other contact electrode to open or close a gap between the contact electrodes.

4. A generator power switching apparatus according to Claim 3 wherein the control unit is configured to control the electrical device to create a voltage on or after formation of a gap between the contact elec-

trodes of the or each vacuum interrupter.

5. A generator power switching apparatus according to any preceding claim wherein an electrical resistance of the mechanical switch is rated so that the current flow path when closed permits at least part of a current flowing between the first and second terminals to flow through the current flow path and thereby minimise a flow of current through the electrical device. 5
6. A generator power switching apparatus according to any preceding claim wherein the electrical device is configured to inhibit a current flowing between the first and second terminals from flowing through the electrical device when the current flow path is closed. 10
7. A generator power switching apparatus according to any preceding claim wherein the mechanical switch is configured to open the current flow path prior to operation of the vacuum interrupter assembly to interrupt a current flowing between the first and second terminals. 15
8. A generator power switching apparatus according to any preceding claim wherein the electrical device is configured to inhibit a current flowing between the first and second terminals from flowing through the electrical device upon formation of a predefined magnitude of current in the vacuum interrupter assembly. 20
9. A generator power switching apparatus according to any preceding claim wherein the electrical device is configured to create a voltage that is at least one or two orders of magnitude higher than an arc voltage generated by the vacuum interrupter assembly. 25
10. A generator power switching apparatus according to any preceding claim wherein the electrical device is configured to be controllable to create a voltage in the range of 1-5 kV or in the range of 5-10 kV. 30
11. A generator power switching apparatus according to any preceding claim wherein the electrical device is a voltage generator or gas filled switch. 35
12. A generator power switching apparatus according to Claim 11 wherein the voltage generator includes at least one semiconductor switching device or a plurality of series-connected semiconductor switching devices. 40
13. A generator power switching apparatus according to any preceding claim wherein the electrical device is connected in series with the vacuum interrupter assembly. 45

14. A generator power switching apparatus according to any preceding claim wherein the current flow path is further connected in parallel with the electrical device. 5
15. A generator power switching apparatus according to any of Claims 1 to 13 wherein the current flow path is further connected in parallel with the first switching assembly. 10
16. A generator power switching apparatus according to any preceding claim wherein the vacuum interrupter assembly includes a plurality of series-connected and/or parallel-connected vacuum interrupters. 15
17. A generator power switching apparatus according to any preceding claim further including a second switching assembly connected in parallel with the first switching assembly between the first and second terminals, the second switching assembly including at least one pulsed power switch, wherein the or each pulsed power switch is configured to be operable to modify a current flowing through the first switching assembly. 20
18. A generator power switching apparatus according to Claim 17 wherein the second switching assembly includes a plurality of series-connected and/or parallel-connected pulsed power switches. 25
19. A generator power switching apparatus according to any preceding claim wherein the electrical device may be configured to create a voltage that increases a voltage drop across the first switching assembly so as to reduce an arc current in the or each vacuum interrupter and thereby cause formation of an unstable arc in the or each vacuum interrupter. 30

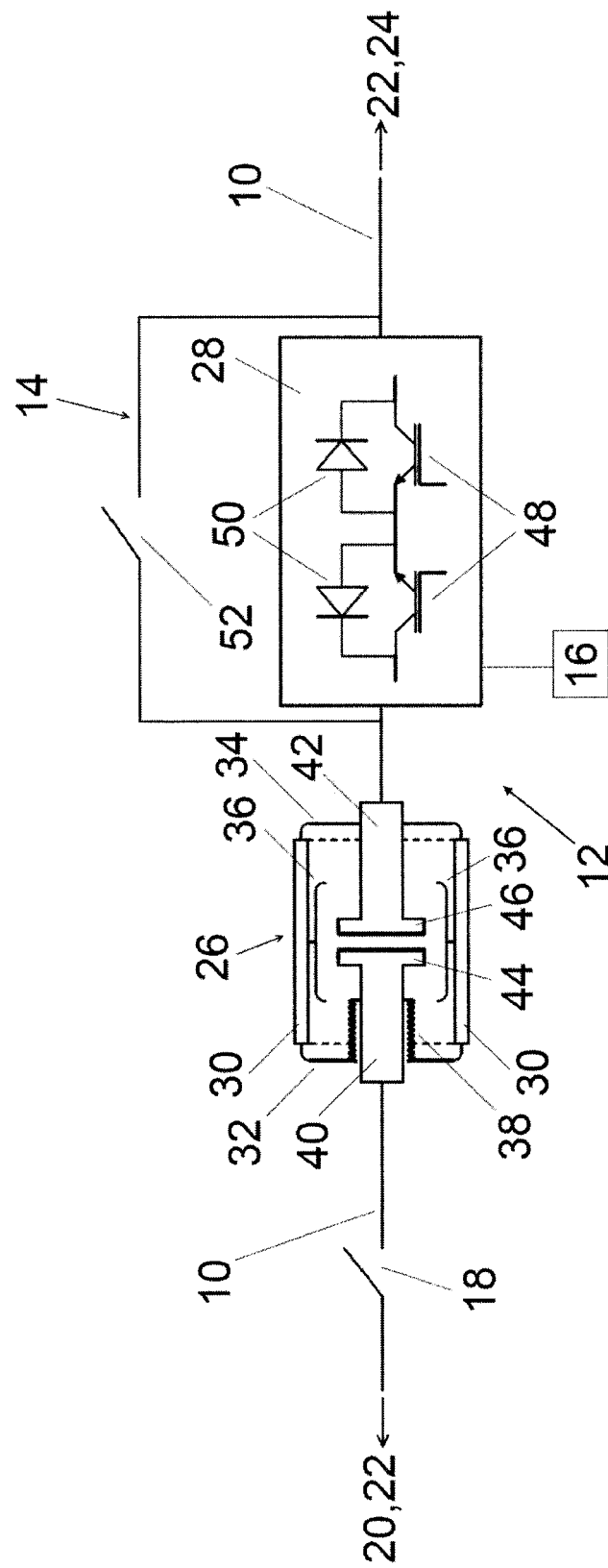


Figure 1a

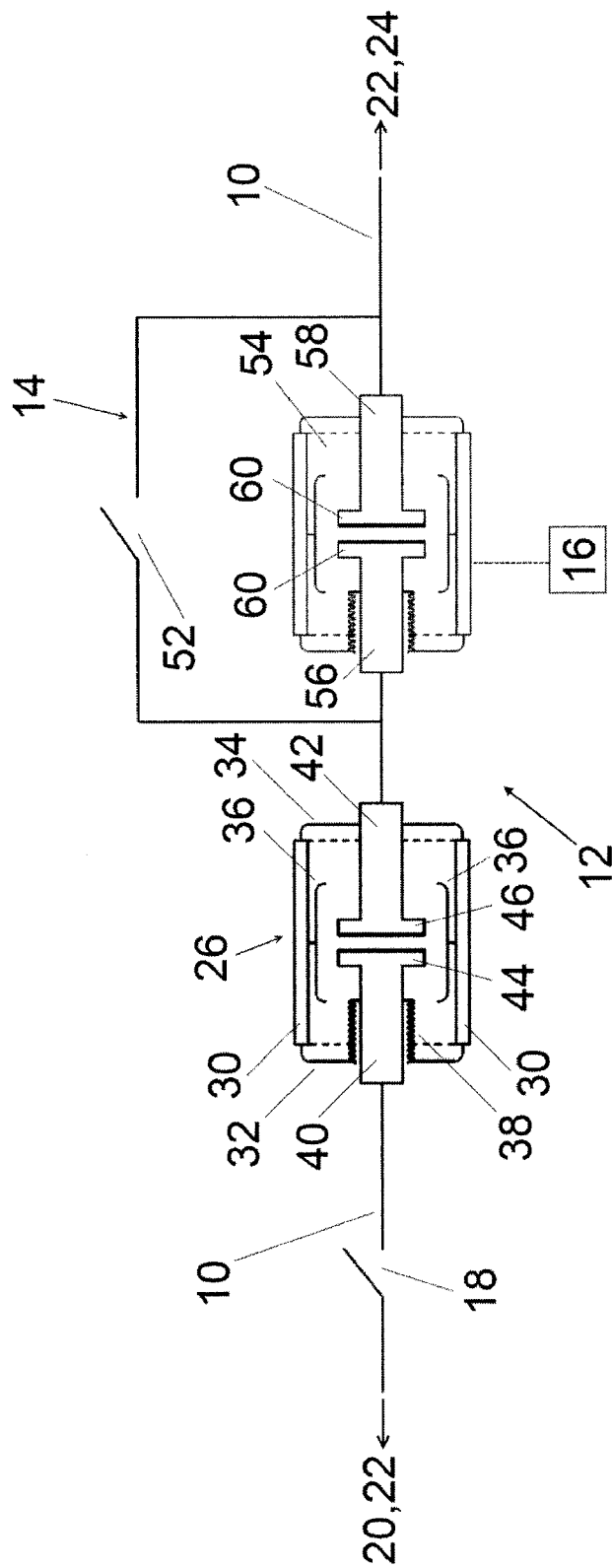


Figure 1b

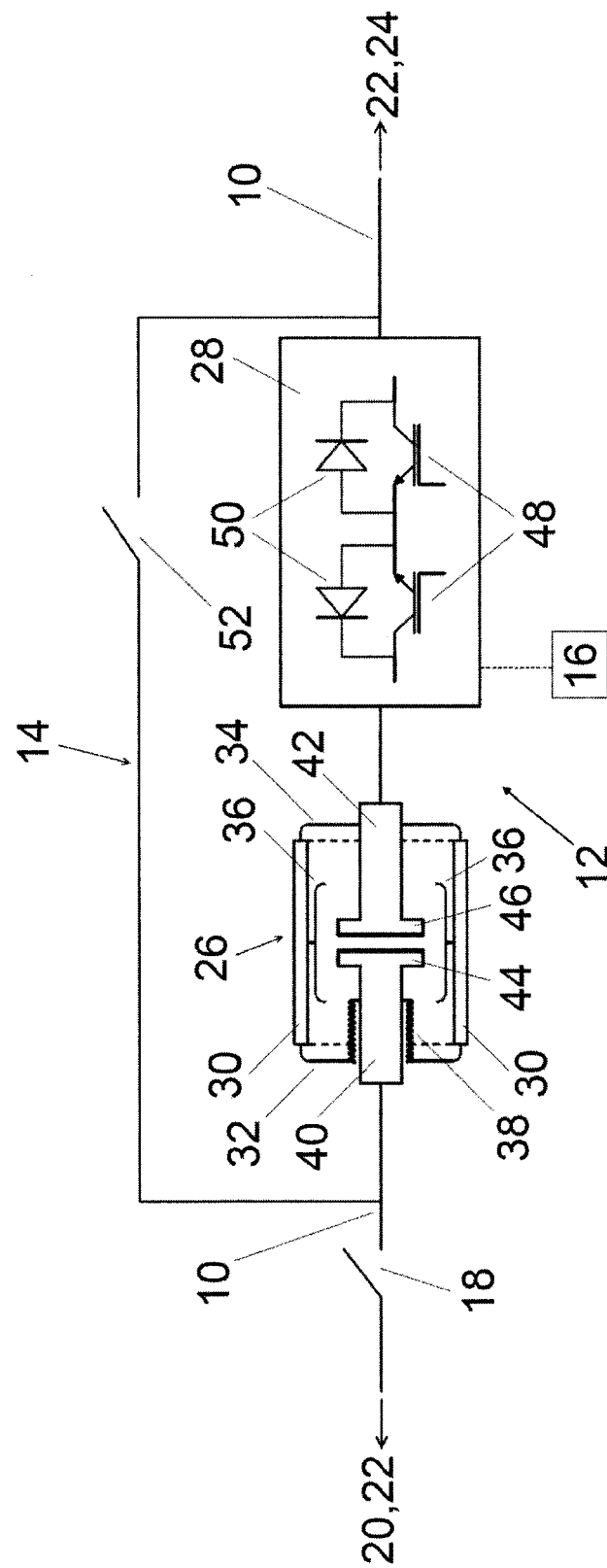


Figure 2

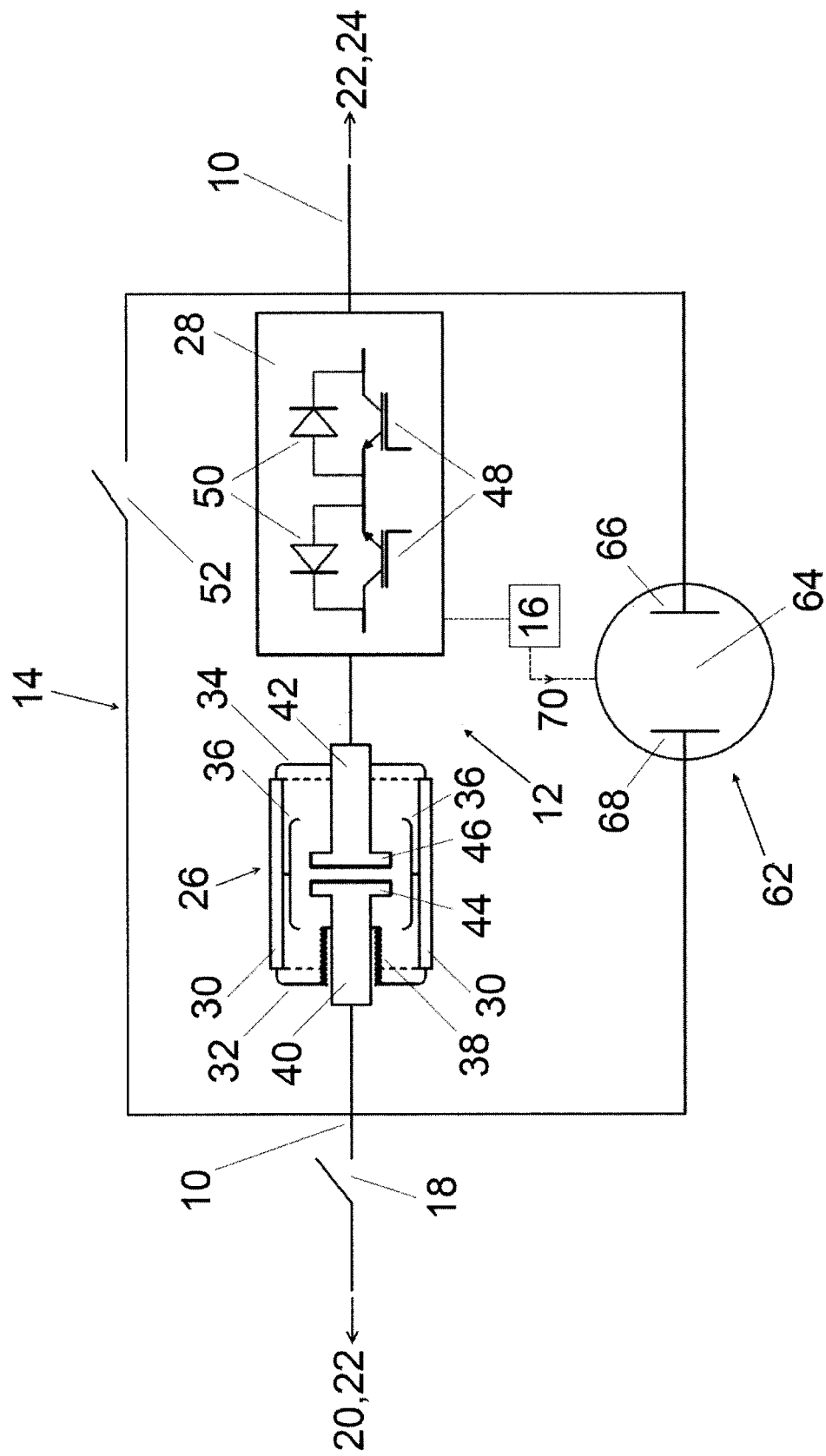


Figure 3



EUROPEAN SEARCH REPORT

Application Number
EP 14 27 5126

5

10

15

20

25

30

35

40

45

50

55

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	WO 2012/159669 A1 (ALSTOM TECHNOLOGY LTD [CH]; PARASHAR RAMA SHANKER [GB]) 29 November 2012 (2012-11-29)	1-16,19	INV. H01H33/04 H01H33/59 H01H33/666 H02H3/00
A	* page 2, line 1 - line 29; figures 3-5 * * page 18, line 27 - page 23, line 15 *	17,18	
A	EP 2 701 254 A1 (ALSTOM TECHNOLOGY LTD [CH]) 26 February 2014 (2014-02-26) * paragraph [0056] - paragraph [0081]; figures 1-3 *	1-19	
A	EP 2 088 606 A2 (Y Y L KK [JP]) 12 August 2009 (2009-08-12) * paragraphs [0040] - [0056], [0078], [0083] - [0085]; figures 11, 18 *	1-19	
A	EP 2 722 859 A1 (ABB TECHNOLOGY AG [CH]) 23 April 2014 (2014-04-23) * paragraph [0022] - paragraph [0024]; figure 3 *	1-19	
			TECHNICAL FIELDS SEARCHED (IPC)
			H01H H02H
The present search report has been drawn up for all claims			
Place of search Munich		Date of completion of the search 3 December 2014	Examiner Rubio Sierra, F
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document			

EPO FORM 1503 (03.82 (P04C01))

**ANNEX TO THE EUROPEAN SEARCH REPORT
ON EUROPEAN PATENT APPLICATION NO.**

EP 14 27 5126

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
The members are as contained in the European Patent Office EDP file on
The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

03-12-2014

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 2012159669 A1	29-11-2012	EP 2715761 A1 WO 2012159669 A1	09-04-2014 29-11-2012
EP 2701254 A1	26-02-2014	EP 2701254 A1 WO 2014029886 A2	26-02-2014 27-02-2014
EP 2088606 A2	12-08-2009	CN 101505054 A EP 2088606 A2 JP 4913761 B2 JP 2008270171 A US 2009201617 A1	12-08-2009 12-08-2009 11-04-2012 06-11-2008 13-08-2009
EP 2722859 A1	23-04-2014	EP 2722859 A1 WO 2014060088 A1	23-04-2014 24-04-2014

REFERENCES CITED IN THE DESCRIPTION

This list of references cited by the applicant is for the reader's convenience only. It does not form part of the European patent document. Even though great care has been taken in compiling the references, errors or omissions cannot be excluded and the EPO disclaims all liability in this regard.

Non-patent literature cited in the description

- **K. H. SCHOENBACH.** A review of opening switch technology for inductive energy storage. *proceedings of The IEEE*, vol. 72 (8), 1019-1040 **[0024]**
- **K.H. SCHOENBACH ; M. KRISTIANSEN.** Diffuse Discharges and Opening Switches - A Review of the Tamarrow Workshops. *Proceeding of 4th IEEE Pulsed Power conference, Albuquerque, New Mexico*, 1983, 26-32 **[0024]**
- **K. H. SCHOENBACH ; M. KRISTIANSEN ; G. SCHAEFER.** A review of opening switch technology for inductive energy storage. *Proceedings of the IEEE*, August 1984, vol. 72 (8), 1019-1040 **[0024]**