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(54) A SWITCHING APPARATUS FOR ELECTRIC POWER DISTRIBUTION GRIDS

(57) A switching apparatus for electric power distribution grids comprising:
- one or more electric poles;
- for each electric pole, at least a fixed contact and a movable contact. The movable contact is reversibly movable between a coupled position, at which said movable contact is coupled with said fixed contact, and an uncoupled position, at which said movable contact is separated from said fixed contact;
- for each electric pole, an arc-breaking assembly comprising an arc-chute arrangement including a plurality of arc-breaking plates. Said arc-breaking plates are electrically disconnected from said fixed contact, said movable contact and other live parts of said electric pole, so that they normally are at a floating voltage potential.

The arc breaking assembly comprises at least an electronic circuit including semiconductor switches, which has a first terminal electrically connected with at least an arc-breaking plate and a second terminal electrically connected with at least another arc-breaking plate.

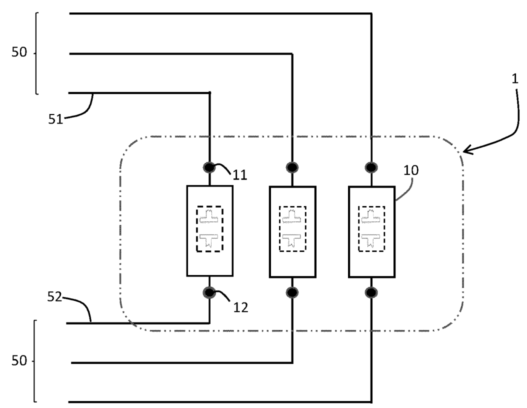

FIG. 1

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Description

[0001] The present invention relates to a switching apparatus for electric power distribution grids, in particular for medium-voltage electric systems.

[0002] Switching apparatuses for electric power distribution grids (e.g. gas-insulated circuit breakers) generally comprise one or more electrical poles, each including electric contacts that can be mutually coupled or uncoupled.

[0003] As is known, during an opening operation of the switching apparatus, electric arcs may occur between the above-mentioned electric contacts under separation, particularly when high line currents (e.g. overload currents or short-circuit currents) are interrupted.

[0004] In order to break line currents circulating along the electric poles, such electric arcs have to be extinguished as quickly as possible. To this aim, switching apparatuses often comprise an arc-chute arrangement positioned near the electric contacts of each electric pole.

[0005] An arc-chute arrangement typically includes a stack of arc-breaking plates normally made of a metallic ferromagnetic material and arranged spaced one from another.

[0006] When the electric contacts of the electric pole separate, the resulting electric arc is driven to the arc-breaking plates by electro-dynamic forces. The arc-breaking plates favour the quench of the electric arc by causing the split of this latter in smaller portions.

[0007] Although switching apparatuses provided with arc-chute arrangements generally perform their functionalities in a rather satisfying way, there is still the need for some improvements, particularly to make more efficient the arc-quenching process. Such a demand appears even more important as insulating gases having lower global warming potential but weaker dielectric properties with respect to SF6 are increasingly used in switching apparatuses.

[0008] The present invention intends to respond to this need, by providing a switching apparatus for electric power distribution grids, according to the following claim 1 and the related dependent claims.

[0009] In a general definition, the switching apparatus, according to the invention comprises:

- one or more electric poles;
- for each electric pole, at least a fixed contact and a movable contact. The movable contact is reversibly movable between a coupled position, at which said movable contact is coupled with said fixed contact, and an uncoupled position, at which said movable contact is separated from said fixed contact;
- for each electric pole, an arc-breaking assembly comprising an arc-chute arrangement including a plurality of arc-breaking plates. Said arc-breaking plates are electrically disconnected from said fixed contact, said movable contact and other live parts of said electric pole, so that they normally are at a floating voltage potential.

[0010] According to the invention, the arc breaking assembly comprises at least an electronic circuit having a first terminal electrically connected with at least an arc-breaking plate and a second terminal electrically connected with at least another arc-breaking plate.

[0011] Said electronic circuit comprises one or more semiconductor switches electrically connected with said first and second terminals and adapted to switch in a conduction state or in an interdiction state depending on a voltage applied thereto.

[0012] Said electronic circuit is configured so that a current is allowed to flow between said first and second terminals, according to a predefined conduction direction, during an opening manoeuvre of said switching apparatus.

[0013] According to some embodiments of the invention, the arc breaking assembly comprises at least an electronic circuit including a single semiconductor switch electrically connected between said first and second terminals, wherein said first terminal is electrically connected with a first arc-breaking plate and said second terminal is electrically connected to a second arc-breaking plate. Said first and second arc-breaking plates are respectively in a proximal position and in a distal position with respect to said fixed contact. In this way, the movable contact passes in proximity of said first and second arc-breaking plates at subsequent instants, during an opening manoeuvre of said switching apparatus.

[0014] Preferably, said semiconductor switch has a current input terminal (e.g. an anode terminal) electrically connected with said first terminal and a current output terminal (e.g. a cathode terminal) electrically connected with said second terminal.

[0015] As an alternative, said semiconductor switch may have a current input terminal (e.g. an anode terminal) electrically connected with said second terminal and a current output terminal (e.g. a cathode terminal) electrically connected with said first terminal.

[0016] According to some embodiments of the invention, the arc breaking assembly comprises at least an electronic circuit including a plurality of semiconductor switches electrically connected in series between said first and second terminals, wherein said first terminal is electrically connected with a first arc-breaking plate and said second terminal is electrically connected to a second arc-breaking plate. Said first and second arc-breaking plates are respectively in a proximal position and in a distal position with respect to said fixed contact.

[0017] Said semiconductor switches may have current input terminals oriented towards said first terminal and current output terminals oriented towards said second terminal.

[0018] Alternatively, said semiconductor switches may have current output terminals oriented towards said first terminal and current input terminals oriented towards said second terminal.

[0019] According to some embodiments of the invention, the arc breaking assembly comprises at least an electronic circuit including a plurality of semiconductor switches electrically connected in parallel between said first and second terminals, wherein said first terminal is electrically connected with a first arc-breaking plate and said second terminal is electrically connected to a second arc-breaking plate. Said first and second arc-breaking plates are respectively in a proximal position and in a distal position with respect to said fixed contact.

[0020] According to some embodiments of the invention, the arc breaking assembly comprises a single electronic circuit having a first terminal electrically connected with a first arc-breaking plate and a second terminal electrically connected with a second arc-breaking plate, wherein said first and second arc-breaking plates are respectively in a proximal position and in a distal position with respect to said fixed contact.

[0021] According to some embodiments of the invention, the arc breaking assembly comprises a plurality of electronic circuits including at least:

- a first electronic circuit having a first terminal electrically connected with a first arc-breaking plate and a second terminal electrically connected with a second arc-breaking plate. Said first and second arc-breaking plates are respectively in a proximal position and in a distal position with respect to said fixed contact;
- a second electronic circuit having a first terminal electrically connected with a third arc-breaking plate and a second terminal electrically connected with a fourth arc-breaking plate. Said third and fourth arc-breaking plates are respectively in a proximal position and in a distal position with respect to said fixed contact.

[0022] According to some embodiments of the invention, the arc breaking assembly comprises at least an electronic circuit having a first terminal electrically connected with a first plurality of first arc-breaking plates and a second terminal electrically connected with a second plurality of arc-breaking plates.

[0023] According to some embodiments of the invention, the arc breaking assembly comprises at least a protection circuit electrically connected in parallel with said at least an electronic circuit. Preferably, the semiconductor switches of said at least an electronic circuit are power diodes. Preferably, the switching apparatus comprises, for each electric pole, an arc chamber including said fixed contact, said movable contact and said arc-chute arrangement. Said arc chamber being filled with an insulating gas.

[0024] Preferably, the switching apparatus a medium-voltage circuit breaker.

[0025] In a further aspect, the present invention relates to a medium-voltage electric system comprising a switching apparatus, as described above.

[0026] Further features and advantages of the present invention will be more apparent from the description of preferred but not exclusive embodiments of the arc chamber for a low-voltage switching apparatus of the present invention, shown by way of examples in the accompanying drawings, wherein:

- Figure 1 schematically represents a switching apparatus, according to the present invention;
- Figure 2 shows different schematic views of an electric pole of the switching apparatus, according to some embodiments of the invention;
- Figures 3-5 schematically show the operation of an arc-breaking assembly included in the electric poles of the switching apparatus, according to an embodiment of the invention;
- Figures 6-7 schematically show the operation of an arc-breaking assembly included in the electric poles of the switching apparatus, according to another embodiment of the invention;
- Figures 8-14 schematically show an arc-breaking assembly included in the electric poles of the switching apparatus, according to other embodiments of the invention.

[0027] With reference to the attached figures, the present invention relates to a switching apparatus 1 for electric power distribution grids.

[0028] The switching apparatus 1 is particularly adapted for AC medium-voltage electric systems and it will be described with particular reference to this kind of applications. However, in principle, it may be used also in electric systems of different types, e.g. DC medium-voltage electric systems or low-voltage electric systems.

[0029] For the purposes of the present invention, the term "low voltage" (LV) relates to operating voltages lower than 1 kV AC and 1.5 kV DC whereas the term "medium voltage" (MV) relates to operating voltages higher than 1 kV up to some tens of kV, e.g. 52 kV AC and 100 kV DC. Figure 1 shows a schematic view the switching apparatus 1.

[0030] The switching apparatus 1 comprises one or more electric poles 10, each comprising a pair of pole contacts 11, 12 that can be electrically coupled with corresponding line conductors 51, 52 of an electric line 50.

[0031] The line conductors 51, 52 of the electric line 50 are, in turn, electrically connectable to an equivalent electric power source (e.g. an electric power feeding or generation system or a section of electric grid) and to an equivalent electric load (e.g. an electric system or apparatus or a section of electric grid).

[0032] The number of electric poles 10 of the switching apparatus 1 may vary, according to the needs. In the embodiments shown in the cited figures, the switching apparatus 1 is of the three-phase type and it comprises three-electric poles. However, according to other embodiments of the invention (not shown), the switching apparatus 1 may include a different number of electric poles depending on the number of electric phases of the electric line 50.

[0033] According to the invention, the switching apparatus 1 comprises, for each electric pole 10, at least a pair of electric contacts 2, 3 that can be mutually coupled or decoupled in order to allow or interrupt the flow of a current through said electric pole.

[0034] In particular, the switching apparatus 1 comprises, for each electric pole 10, at least a fixed contact 2 and at least a movable contact 3.

[0035] According to some embodiments of the invention (figure 2), the switching apparatus 1 comprises, for each electric pole 10, a single fixed contact and a single movable contact that can be mutually coupled or decoupled (single current breaking configuration).

[0036] According to other embodiments of the invention (not shown), the switching apparatus 1 comprises, for each electric pole 10, a pair of fixed contacts and a pair of movable contacts that can be mutually coupled or decoupled (double current breaking configuration).

[0037] Each movable contact 3 of the switching apparatus is reversibly movable between a coupled position, at which it is coupled with the corresponding fixed contact 2, and an uncoupled position, at which it is separated from the corresponding fixed contact 2.

[0038] When each movable 3 is in a coupled position, the switching apparatus 1 is in a closed state and line currents can flow along the electric poles 10 whereas, when each movable 3 is in an uncoupled position, the switching apparatus 1 is in an open state and no line currents can flow along the electric poles 10.

[0039] A transition from a closed state to the open state forms an opening manoeuvre of the switching apparatus 1 whereas a transition from an open state to a closed state forms a closing manoeuvre of the switching apparatus 1.

[0040] When the switching apparatus 1 carries out an opening manoeuvre, each movable contact 3 moves from the coupled position towards the uncoupled position according to a given direction of movement M.

[0041] When the switching apparatus 1 carries out a closing operation, each movable contact 3 moves from the uncoupled position to the coupled position according to an opposite direction of movement.

[0042] According to some embodiments of the invention (figure 2), each movable contact 3 reversibly moves between the above-mentioned coupled and uncoupled positions by carrying out suitable opposite rotational movements.

[0043] According to other embodiments of the invention (not shown), each movable contact 3 reversibly moves the above-mentioned coupled and uncoupled positions by carrying out suitable opposite linear movements.

[0044] Conveniently, the switching apparatus 1 comprises actuating means (not shown) operatively coupled with the movable contacts 3 through suitable motion transmission means (not shown) and adapted to actuate said movable contacts during an opening or closing manoeuvre.

[0045] In general, the electric contacts 2, 3 and the above-mentioned actuating means and motion transmission means of the switching apparatus 1 may be realized according to solutions of known type and they will be described hereinafter in relation to the aspects of interest of the invention only, for the sake of brevity.

[0046] Besides, the switching apparatus 1 may comprise a variety of additional components (most of them are not shown in the cited figures), which may be realized according to solutions of known type. Also, these additional components will be not described hereinafter, for the sake of brevity.

[0047] The switching apparatus 1 comprises, for each electric pole 10, an arc-breaking assembly 4. The arc-breaking assembly 4 comprises an arc-chute arrangement 4A including a plurality of arc-breaking plates 400 arranged in proximity of the electric contacts 2, 3.

[0048] The arc-breaking plates 400 are conveniently stacked side by side and spaced one from another along a given stack direction that is conveniently oriented according to the trajectory followed by the movable contact 3 during the opening and closing manoeuvres of the switching apparatus.

[0049] The arc-breaking plates 400 are thus arranged at positions having increasingly relative distances with respect to the fixed contact 2.

[0050] Preferably, the arc-breaking plates 400 are made, at least partially, of a ferromagnetic material, e.g. mild steel.

[0051] The arc-breaking plates 400 may be shaped according to the needs. As an example, each arc-breaking plate may have a rectangular shape with a grooved side in proximal position with respect to the electric contacts 2, 3. In this way, the movable contact 3 can pass in proximity to the arc-breaking plates 400 during an opening or closing manoeuvre of the switching apparatus. Preferably, the arc-chute arrangement 4A comprises one or more insulating support elements 45 adapted to maintain the arc-breaking plates 400 in their stacked position and adapted to fix the arc-assembly 4 to a support (not shown) of the corresponding electric pole 10.

[0052] The arc-breaking plates 400 are electrically disconnected from the electric contacts 2, 3 of the corresponding electric pole 10 and from other live parts of said electric pole. Therefore, they are normally at a floating voltage potential during the operation of the switching apparatus 1. For the sake of clarity, it is specified that the term "live parts" describes components of the switching apparatus, which have a line voltage during the operation of the switching apparatus. It is further specified that the term "floating voltage potential" describes a voltage potential that is not directly tied to a given voltage reference during the operation of the switching apparatus. Preferably, the switching apparatus 1 is of the gas-insulated type, e.g. a gas-insulated medium-voltage circuit breaker. In this case, each electric pole 10 conveniently comprises an arc chamber (not shown) having an internal volume, in which the fixed contact 2, the movable contact 3 and at least the arc-chute arrangement 4A are accommodated.

[0053] Preferably, such an arc chamber is filled with an insulating gas, for example SF6.

[0054] More preferably, however, said arc chamber is filled with a more environment-friendly insulating gas.

[0055] For example, it may be used an insulating gas selected in a group including CO2, O2, N2, H2, air, N_2O, a hydrocarbon compound (in particular CH4), a perfluorinated compound, a partially hydrogenated organofluorine compound, or mixture products thereof.

[0056] As another example, it may be used an insulating gas including a background gas selected in a group including CO_2, O_2, N_2, H_2, air, in a mixture with an organofluorine compound selected in a group including fluoroether, oxirane, fluoramine, fluoroketone, fluoroolefin, fluoronitrile, and mixture and/or decomposition products thereof.

[0057] An important aspect of the invention consists in that each arc breaking assembly 4 comprises at least an electronic circuit 40, 40A, 40B electrically connected with a pair of different arc-breaking plates 41, 42, 43, 44.

[0058] The electronic circuit 40, 40A, 40B has a first terminal T1 electrically connected with an arc-breaking plate 41, 43 and a second terminal T2 electrically connected with another arc-breaking plate 42, 44.

[0059] The electronic circuit 40, 40A, 40B comprises at least one or more semiconductor switches D1, D2, DN electrically connected with the first and second terminals T1, T2.

[0060] Each semiconductor switch D1, D2, DN is adapted to switch in a conduction state or in an interdiction state depending on a voltage applied thereto.

[0061] When it is in a conduction state, each semiconductor switch allows the flow of a current according to a predefined conduction direction, whereas, when it is in an interdiction state, each semiconductor switch blocks the flow of a current passing therethrough.

[0062] Preferably, the semiconductor switches D1, D2, DN are power diodes. In principle, however, they may be of different type, e.g. thyristors or power transistors, provided that they operate as power diodes.

[0063] In general, the electronic circuit 40, 40A, 40B is configured in such a way that a current I_{ARC} can flow between the first and second terminals T1, T2, according to a predefined conduction direction, during the operation of the switching apparatus 1, in particular during an opening manoeuvre thereof.

[0064] The current I_{ARC} circulating along the electronic is an arc current generated by electric arcs arising between the electric contacts 2, 3 under separation, during an opening manoeuvre of the switching apparatus 1.

[0065] As it will be more apparent from the following, during an opening manoeuvre of the switching apparatus 1, the semiconductor switches D1, D2, DN of the electronic circuit 40, 40A, 40B are initially in an interdiction state.

[0066] The arc current I_{ARC}, which is generated by electric arcs resulting from the separation of the electric contacts 2-3, initially starts circulating through the arc-breaking plates 400 according to direction M of the separation movement of the movable contact 3.

[0067] At some point of the opening manoeuvre, when the first and second terminals T1, T2 are subject to a suitable voltage difference, the semiconductor switches D1, D2, DN switch in a conduction state and the arc current I_{ARC} starts circulating along the electronic circuit 40 instead of passing through the arc-breaking plates 400.

[0068] Such a commutation of the arc current I_{ARC} from the arc-breaking plates to the electronic circuit 40 allows quickly extinguishing electric arcs between the arc-breaking plates. The insulating gas between the arc-breaking plates can therefore cool down, thereby improving its dielectric properties (it becomes less conductive) and preventing the formation of further decomposition products.

[0069] Additionally, the arc current I_{ARC} circulating along the electronic circuit 10 can be interrupted more effectively as the semiconductor switches D1, D2, DN ensure a high interruption power, even in harsh interruption conditions.

[0070] Thanks to the electronic circuit 40, 40A, 40B equipped with semiconductor switches D1, D2, DN operating as power diodes, the arc-breaking assembly 4 shows improved current-breaking performances with respect to corresponding devices of the state of the art.

[0071] Besides, it is evidenced that the presence of the semiconductor switches D1, D2, DN does not jeopardize the galvanic insulation provided by the switching apparatus 1. In fact, the electronic circuit 40 has the terminals T1, T2 electrically connected to different arc-breaking plates 41, 42, 43, 44 electrically disconnected from the electric contacts 2, 3 and other live parts, thereby normally operating at a floating voltage potential (in particular when the switching apparatus is in an open state).

[0072] Figures 3-4 show an embodiment of the invention, in which the arc-breaking assembly 4 comprises an electronic circuit 40 including a single semiconductor switch D1 (power diode). The semiconductor switch D1 has a current input terminal (anode terminal) and a current output terminal (cathode terminal) electrically connected with the first terminal T1 and the second terminal T2 of the electronic circuit 40, respectively. The first and second terminals T1, T2 are in turn electrically connected with first and second arc-breaking plates 41, 42 respectively.

[0073] The arc-breaking plates 41, 42 are positioned in a proximal position and in a distal position with respect to the fixed contact 2 of the electric pole 10. In this way, the movable contact 3 passes first in proximity of the first arc-breaking plate 41 and subsequently in proximity of the second arc-breaking plate 42, during an opening manoeuvre of the switching apparatus.

[0074] Since it has its current input and output terminals (anode and cathode) electrically connected to the arc-breaking plates 41, 42 (through the first and second terminals T1, T2 of the electronic circuit 10), respectively, the semiconductor switch D1 (power diode) is oriented in agreement to the direction of movement M of the movable contact 3, during an opening manoeuvre of the switching apparatus.

[0075] The operation of the arc-breaking assembly 4 of figures 3-4 is now described in more details referring also to figure 5.

[0076] When the switching apparatus 1 is in a closed state, the semiconductor switch D1 is in an interdiction state as the arc-breaking plates 41, 42 are at the same (floating) voltage potential. During an opening manoeuvre, when the movable contact 3 separates from the fixed contact 2 (figure 5 - instant to), electric arcs arise between the electric contacts 2, 3 and reach the arc-breaking plates 400.

[0077] As soon as the movable contact 3 reaches the arc-breaking plates 400, an (AC) arc current I_{ARC} starts circulating through the arc-breaking plates 400 following the direction of movement M of the movable contact 3 (figure 3).

[0078] The arc current I_{ARC} naturally follows a current path extending through the gap between the fixed contact 2 and the first arc-breaking plate reached by the movable contact 3, through the arc-breaking plates reached by the movable contact 3 and through the gap between the last arc-breaking plate reached by the movable contact 3 and the movable contact itself (figure 3). Initially, the power diode D1 remains in an interdiction state as both the first and second terminals T1, T2 or at least the second terminal T2 of the electronic circuit 10 are at a floating voltage potential. Therefore, the arc current I_{ARC} follows the natural current path through the arc-breaking plates 400 already reached by the movable contact 3.

[0079] When the movable contact 3 reaches both the first and second arc-breaking plates 41, 42 according to the direction of movement M, the first and second terminals T1, T2 are not at a floating voltage potential anymore.

[0080] A forward bias voltage V_D (more precisely a forward bias voltage difference) is applied between the first and second terminals T1, T2 of the electronic circuit 10 (and therefore the current input and output terminals of the semiconductor switch D1) since the arc-breaking plates 41, 42 are now positioned at different points of a same current path having a relatively high equivalent impedance.

[0081] In general, the bias voltage V_D applied between the first and second terminals T1, T2 of the electronic circuit 10 is given by the following relation:

$$V_D = \alpha V_{RV}$$

where V_{RV} is the voltage difference between the electric contacts 2, 3 under separation during the opening manoeuvre and α (with $0 < \alpha < 1$) is a parameter that depends on the configuration of the equivalent capacitance between the arc-breaking plates 41, 42. In general, the parameter α takes a minimum value when the arc-breaking plates 41, 42 are side by side and a maximum value when the arc-breaking plates 41, 42 are positioned at opposite sides of the arc-chute arrangement 4A.

[0082] If it is higher than the threshold voltage of the semiconductor switch D1 (power diode), the forward bias voltage V_D between the first and second terminals T1, T2 makes the semiconductor switch D1 to switch in a conduction state (figure 5 - instant ti).

[0083] In this situation, the semiconductor switch D1 provides an alternative low-impedance current path to the arc current I_{ARC}, which thus moves away from the arc-breaking plates 400 and starts circulating between the first and second terminals T1, T2.

[0084] The arc current I_{ARC} follows now an alternative current path extending through the gap between the fixed contact 2 and the first arc-breaking plate reached by the movable contact 3, through the first and second terminals T1, T2 and through the gap between the last arc-breaking plate reached by the movable contact 3 and the movable contact itself (figure 4).

[0085] When the arc current I_{ARC} reaches a zero-current value (figure 5 - instant t2), the semiconductor switch D1 switches in an interdiction state as a reverse bias voltage $-V_D$ is applied between the first and second terminals T1, T2 of the electronic circuit 10 (and therefore the current input and output terminals of the semiconductor switch D1). The arc current I_{ARC} is thus interrupted and a galvanic separation is ensured between the fixed contact 2 and the movable contact 3. Figure 6 shows another embodiment of the invention, in which the arc-breaking assembly 4 comprises an electronic circuit 40 including a single semiconductor switch D1 (power diode). In this case, however, the semiconductor switch D1 has the current input and output terminals (anode and cathode) electrically connected with the second terminal T2 and the first terminal T1 of the electronic circuit 40, respectively. The first and second terminals T1, T2 are in turn electrically connected with first and second arc-breaking plates 41, 42 respectively.

[0086] The arc-breaking plates 41, 42 are positioned in a proximal position and in a distal position with respect to the fixed contact 2 of the electric pole 10 as in the embodiment of figures 3-4.

[0087] Since it has the current input and output terminals (anode and cathode) electrically connected to the arc-breaking plates 41, 42 (through the first and second terminals T1, T2 of the electronic circuit 10), respectively, the semiconductor switch D1 is oriented in opposition to the direction of movement M of the movable contact 3, during an opening manoeuvre of the switching apparatus.

[0088] The operation of the arc-breaking assembly 4 of figure 6 is now described in more details referring also to figure 7.

[0089] When the switching apparatus 1 is in a closed state, the semiconductor switch D1 is in an interdiction state as the arc-breaking plates 41, 42 are at the same (floating) voltage potential. During an opening manoeuvre, when the movable contact 3 separates from the fixed contact 2 (figure 7 - instant to), electric arcs arise between the electric contacts 2, 3 and reach the arc-breaking plates 400. An (AC) arc current I_{ARC} starts circulating through the arc-breaking plates 400 following the direction of movement M of the movable contact 3 (figure 3).

[0090] In this situation, the power diode D1 remains in an interdiction state as a reverse bias voltage-V_D is applied between the first and second terminals T1, T2. Therefore, the arc current I_{ARC} follows its natural current path configured as illustrated above.

[0091] When the arc current I_{ARC} overtakes the first zero-current value (figure 7 - instant t3), a forward bias voltage V_D is applied between the first and second terminals T1, T2. However, such a direct voltage V_D does not initially exceed the threshold-voltage of the power diode D1. The power diode D1 therefore initially remains in an interdiction state.

[0092] When the forward bias voltage V_D between the first and second terminals T1, T2 exceeds the threshold-voltage (figure 7 - instant t4), the semiconductor switch D1 switches in a conduction state, thereby providing an alternative low-impedance current path for the arc current I_{ARC}.

[0093] In this situation, the arc current I_{ARC} moves away from the arc-breaking plates 400 to the electronic circuit 40 and starts circulating between the first and second terminals T1, T2. The arc current I_{ARC} thus follows an alternative current path configured as illustrated above.

[0094] When the arc current I_{ARC} reaches the next zero-current value (figure 7 - instant t_5), the semiconductor switch D1 switches in an interdiction state as a reverse bias voltage -V_D is again applied between the first and second terminals T1, T2 of the electronic circuit 10. The arc current I_{ARC} is thus interrupted.

[0095] Figure 8 shows an embodiment of the invention, according to which the electronic circuit 40 of the arc-breaking assembly 4 includes multiple semiconductor switches D1, D2, DN (power diodes) electrically connected in series between the first and second terminals T1, T2.

[0096] The semiconductor switches D1, D2, DN have their current input and output terminals (anodes and cathodes) oriented towards the first terminal T1 and the second terminal T2, respectively. The first and second terminals T1, T2 are in turn electrically connected with first and second arc-breaking plates 41, 42 respectively.

[0097] The arc-breaking plates 41, 42 are positioned in a proximal position and in a distal position with respect to the fixed contact 2 of the electric pole 10 as in the embodiments of figures 3-4, 6. The semiconductor switches D1, D2, DN are therefore oriented according to the direction of movement M of the movable contact 3, during an opening manoeuvre of the switching apparatus.

[0098] As it can be easily understood, the operation of the arc-breaking assembly 4 is substantially similar to that one of the embodiments of figures 3-4. Therefore, it will not here be described in more details for the sake of brevity.

[0099] Figure 9 shows another embodiment of the invention, according to which the electronic circuit 40 of the arc-breaking assembly 4 includes multiple semiconductor switches D1, D2, DN (power diodes) electrically connected in series between the first and second terminals T1, T2. The power diodes D1, D2, DN have their anodes and cathodes oriented towards the second terminal T2 and the first terminal T1, respectively.

[0100] The arc-breaking plates 41, 42 are positioned in a proximal position and in a distal position with respect to the fixed contact 2 of the electric pole 10.

[0101] The power diodes D1, D2, DN are therefore oriented opposite to the direction of movement M of the movable contact 3, during an opening manoeuvre of the switching apparatus.

[0102] As it can be easily understood, the operation of the arc-breaking assembly 4 is substantially similar to that one of the embodiment of figure 6. Therefore, it will not here be described in more details for the sake of brevity.

[0103] The embodiments of figures 8-9 are particularly advantageous as they allow using semiconductor switches (power diodes) of smaller size (thereby less expensive), since the voltage V_{Di} applied between the current input and output terminals (anode and cathode) of each semiconductor switch is considered lowered. Such a voltage is substantially given by the following relation:

$$V_{Di} = V_D/N$$

where V_D is the bias voltage applied between the first and second terminals T1, T2 and N is the number of semiconductor switches electrically connected in series.

[0104] According to other embodiments of the invention (not shown), the electronic circuit 40 of the arc-breaking assembly 4 may include multiple semiconductor switches D1, D2, DN (e.g. power diodes) electrically connected in parallel between the first and second terminals T1, T2.

[0105] As it can be easily understood, in this case, the operation of the arc-breaking assembly 4 is substantially similar to the operation of the embodiment of figures 3-4. Therefore, it will not here be described in more details for the sake of brevity.

[0106] As the skilled person will certainly appreciate, further configurations of the electronic circuit 40 are possible, provided that they ensure the circulation of an arc current I_{ARC} between the first and second terminals T1, T2, according to a predefined conduction direction, during an opening manoeuvre of the switching apparatus.

[0107] Figures 3, 4, 6, 8-9 show embodiments of the invention, according to which the arc-breaking assembly 4 comprises a single electronic circuit 40 configured as described above.

[0108] Figures 10-12 show embodiments of the invention, according to which the arc-breaking assembly 4 comprises multiple electronic circuits 40A, 40B configured as described above.

[0109] According to these embodiments of the invention, the arc-breaking assembly 4 comprises a first electronic circuit 40A, which has a first terminal T1 electrically connected with a first arc-breaking plate 41 and a second terminal T2 electrically connected with a second arc-breaking plate 42. The arc-breaking plates 41, 42 are positioned in a proximal position and in a distal position with respect to the fixed contact 2 of the electric pole 10.

[0110] The arc-breaking assembly 4 further comprises a second electronic circuit 40B, which has a corresponding first terminal T1 electrically connected with a third arc-breaking plate 43 and a corresponding second terminal T2 electrically connected with a fourth arc-breaking plate 44. The arc-breaking plates 43, 44 are positioned in a proximal position and in a distal position with respect to the fixed contact 2 of the electric pole 10.

[0111] In the embodiment of figure 10, the electronic circuits 40A, 40B are configured in such a way to conduct an arc current I_{ARC} according to a same predefined direction, during the opening manoeuvre of the switching apparatus.

[0112] In the embodiments of figure 11-12, the electronic circuits 40A, 40B are configured in such a way to conduct an arc current I_{ARC} according to opposite predefined directions, during the opening manoeuvre of the switching apparatus.

[0113] According to the embodiments of figures 10-11, the first, second, third and fourth arc-breaking plates 41, 42, 43, 44 are positioned at increasing distances from the fixed contact 2, respectively. In this way, the movable contact 3 passes in proximity of said arc-breaking plates at subsequent instants, during an opening manoeuvre of the switching apparatus.

[0114] In the embodiment of figure 12, the order of the arc-breaking plates 41, 42, 43, 44 has been changed as the relative positions of second and third arc-breaking plates have been inverted.

[0115] As it can be easily understood, in the above-mentioned embodiments of the invention, the operation of the arc-breaking assembly 4 is substantially similar to the operation the embodiment of figures 3-4 or to the operation of the embodiment of figure 6 depending on how the electronic circuits 40A, 40B are configured. Therefore, it will not here be described in more details for the sake of brevity.

[0116] As the skilled person will certainly appreciate, further configurations including multiple electronic circuits 40A, 40B are possible provided that each electronic circuit ensures the circulation of an arc current I_{ARC} between the first and second terminals T1, T2, according to a predefined conduction direction, during an opening manoeuvre of the switching apparatus. Figure 13 shows an embodiment of the invention, in which the electronic circuit 40 has a first terminal T1 electrically connected with a first plurality of first arc-breaking plates 41, 43 and a second terminal T2 electrically connected with a second plurality of arc-breaking plates 42, 44. Also in this case, the operation of the arc-breaking assembly 4 is substantially similar to the operation the embodiment of figures 3-4 or to the operation of the embodiment of figure 6 depending on how the electronic circuit 40 is configured. Therefore, it will not here be described in more details for the sake of brevity.

[0117] As the skilled person will certainly appreciate, further configurations including the electrical connection of each terminal T1, T2 to multiple arc-breaking plates are possible.

[0118] According to some embodiments of the invention, the arc breaking assembly 4 comprises one or more protection circuits 49, each electrically connected in parallel with a corresponding electronic circuit 40.

[0119] Figure 14 shows an embodiment of the invention, in which the arc-breaking assembly 4 comprises a protection circuit 49 (e.g. including a varistor) electrically connected in parallel to electronic circuit 40. This solution is quite advantageous as it prevents the electronic circuit 40 from being subject to excessive voltage spikes at the terminals T1, T2.

[0120] The switching apparatus 1, according to the invention, provides relevant advantages with respect to corresponding known switching systems of the state of the art.

[0121] The switching apparatus 1 includes an arc-breaking assembly 4 having improved current breaking capabilities.

[0122] The arrangement of an electronic circuit 10 configured as described above allows quickly extinguishing electric arcs between the arc-breaking plates, thereby improving the dielectric properties of the insulating gases therebetween.

[0123] Additionally, being managed by an electronic circuit 10 including semiconductor switches, the arc current I_{ARC} circulating between the fixed contact 2 and the movable contact 3 can be effectively interrupted due to the high interruption power provided by said semiconductor switches. Thus, the switching apparatus 1 proves particularly effective when critical line currents (e.g. short-circuit currents or overload currents) have to be interrupted during an opening manoeuvre.

[0124] The switching apparatus 1 is particularly adapted for use in AC medium-voltage applications. However, it may be conveniently used also in applications of different type.

[0125] The switching apparatus 1 is relatively easy and cheap to manufacture at industrial level with well-established manufacturing techniques. It may therefore be manufactured at competitive costs with similar switching systems of the state of the art.

Claims

1. A switching apparatus (1) for electric power distribution grids comprising:

   - one or more electric poles (10);
   - for each electric pole, at least a fixed contact (2) and a movable contact (3), said movable contact being reversibly movable between a coupled position, at which said movable contact is coupled with said fixed contact, and an uncoupled position, at which said movable contact is separated from said fixed contact;
   - for each electric pole, an arc-breaking assembly (4) comprising an arc-chute arrangement (4A) including a plurality of arc-breaking plates (41, 42, 43, 44), said arc-breaking plates being electrically disconnected from said fixed contact, said movable contact and other live parts of said electric pole;

   characterised in that said arc breaking assembly (4) comprises at least an electronic circuit (40, 40A, 40B) having a first terminal (T1) electrically connected with at least an arc-breaking plate (41, 43) and a second terminal (T2) electrically connected with at least another arc-breaking plate (42, 44), said electronic circuit comprising one or more semiconductor switches (D1, D2, DN) electrically connected with said first and second terminals (T1, T2) and adapted to switch in a conduction state or in an interdiction state depending on a voltage applied thereto, said electronic circuit being configured so that a current (I_{ARC}) can flow between said first and second terminals (T1, T2), according to a predefined conduction direction, during an opening manoeuvre of said switching apparatus.

2. Switching apparatus, according to claim 1, **characterised in that** said arc breaking assembly (4) comprises at least an electronic circuit (40, 40A, 40B) including a single semiconductor switch (D1) electrically connected between said first and second terminals (T1, T2), wherein said first and second terminals are electrically connected to first and second arc-breaking plates (41, 42), respectively, wherein said first and second arc-breaking plates (41, 42) are respectively in a proximal position and in a distal position with respect to said fixed contact (2).

3. Switching apparatus, according to claim 2, **characterised in that** said semiconductor switch (D1) has a current input terminal electrically connected with said first terminal (T1) and a current output terminal electrically connected with said second terminal (T2).

4. Switching apparatus, according to claim 2, **characterised in that** said semiconductor switch (D1) has a current output terminal electrically connected with said first terminal (T1) and a current input terminal electrically connected with said second terminal (T2).

5. Switching apparatus, according to one or more of the previous claims, **characterised in that** said arc breaking assembly (4) comprises at least an electronic circuit (40, 40A, 40B) including a plurality of semiconductor switches (D1, D2, DN) electrically connected in series between said first and second terminals (T1, T2), wherein said first and second terminals are electrically connected to first and second arc-breaking plates (41, 42), respectively, wherein said first and second arc-breaking plates (41, 42) are respectively in a proximal position and in a distal position with respect to said fixed contact (2).

6. Switching apparatus, according to claim 5, **characterised in that** said semiconductor switches (D1, D2, DN) have current input terminals oriented towards said first terminal (T1) and current output terminals oriented towards said second terminal (T2).

7. Switching apparatus, according to claim 5, **characterised in that** said semiconductor switches (D1, D2, DN) have current output terminals oriented towards said first terminal (T1) and current input terminals oriented towards said second terminal (T2).

8. Switching apparatus, according to one or more of the previous claims, **characterised in that** said arc breaking assembly (4) comprises at least an electronic circuit (40, 40A, 40B) including a plurality of semiconductor switches (D1, D2, DN) electrically connected in parallel between said first and second terminals (T1, T2), wherein said first and second terminals are electrically connected to first and second arc-breaking plates (41, 42), respectively, wherein said first and second arc-breaking plates (41, 42) are respectively in a proximal position and in a distal position with respect to said fixed contact (2).

9. Switching apparatus, according to one or more of the previous claims, **characterised in that** said arc breaking assembly (4) comprises a single electronic circuit (40) having a first terminal (T1) electrically connected with a first arc-breaking plate (41) and a second terminal (T2) electrically connected with a second arc-breaking plate (42), wherein said first and second arc-breaking plates (41, 42) are respectively in a proximal position and in a distal position with respect to said fixed contact (2).

10. Switching apparatus, according to one or more of the claims from 1 to 8, **characterised in that** said arc breaking assembly (4) comprises at least:

- a first electronic circuit (40A) having a first terminal (T1) electrically connected with a first arc-breaking plate (41) and a second terminal (T2) electrically connected with a second arc-breaking plate (42), wherein said first and second arc-breaking plates (41, 42) are respectively in a proximal position and in a distal position with respect to said fixed contact (2);
- a second electronic circuit (40B) having a first terminal (T1) electrically connected with a third arc-breaking plate (43) and a second terminal (T2) electrically connected with a fourth arc-breaking plate (44), wherein said third and fourth arc-breaking plates (43, 44) are respectively in a proximal position and in a distal position with respect to said fixed contact (2).

11. Switching apparatus, according to claim 10, **characterised in that** said conduct an arc current (I_{ARC}) according to a same predefined direction, during the opening manoeuvre of the switching apparatus.

12. Switching apparatus, according to claim 10, **characterised in that** said conduct an arc current (I_{ARC}) according to opposite predefined directions, during the opening manoeuvre of the switching apparatus.

13. Switching apparatus, according to one or more of the previous claims, **characterised in that** said arc breaking assembly (4) comprises at least an electronic circuit having a first terminal (T1) electrically connected with a first plurality of first arc-breaking plates (41, 43) and a second terminal (T2) electrically connected with a second plurality of arc-breaking plates (42, 44).

14. Switching apparatus, according to one or more of the previous claims, **characterised in that** said arc breaking assembly (4) comprises at least a protection circuit (49) electrically connected in parallel with said at least an electronic circuit (40).

15. A switching apparatus, according to one or more of the previous claims, **characterised in that** said semiconductor switches (D1, D2, DN) are power diodes.

16. A switching apparatus, according to one or more of the previous claims, **characterised in that** it comprises, for each electric pole, an arc chamber (5) including said fixed contact (2), said movable contact (3) and said arc-chute arrangement (4A), said arc chamber being filled with an insulating gas.

17. A switching apparatus, according to one or more of the previous claims, **characterised in that** it is a medium-voltage circuit breaker.

18. A medium-voltage electric system comprising a switching apparatus (1), according to one or more of the previous claims.

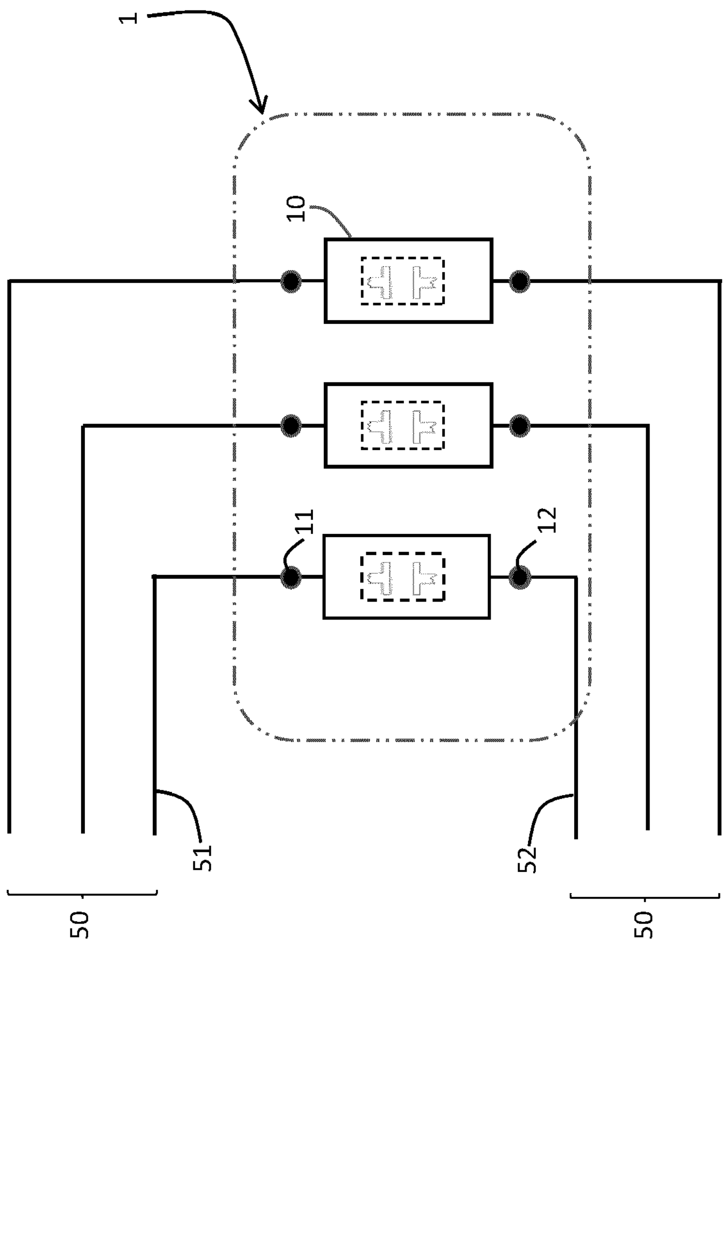


FIG. 1

FIG. 2

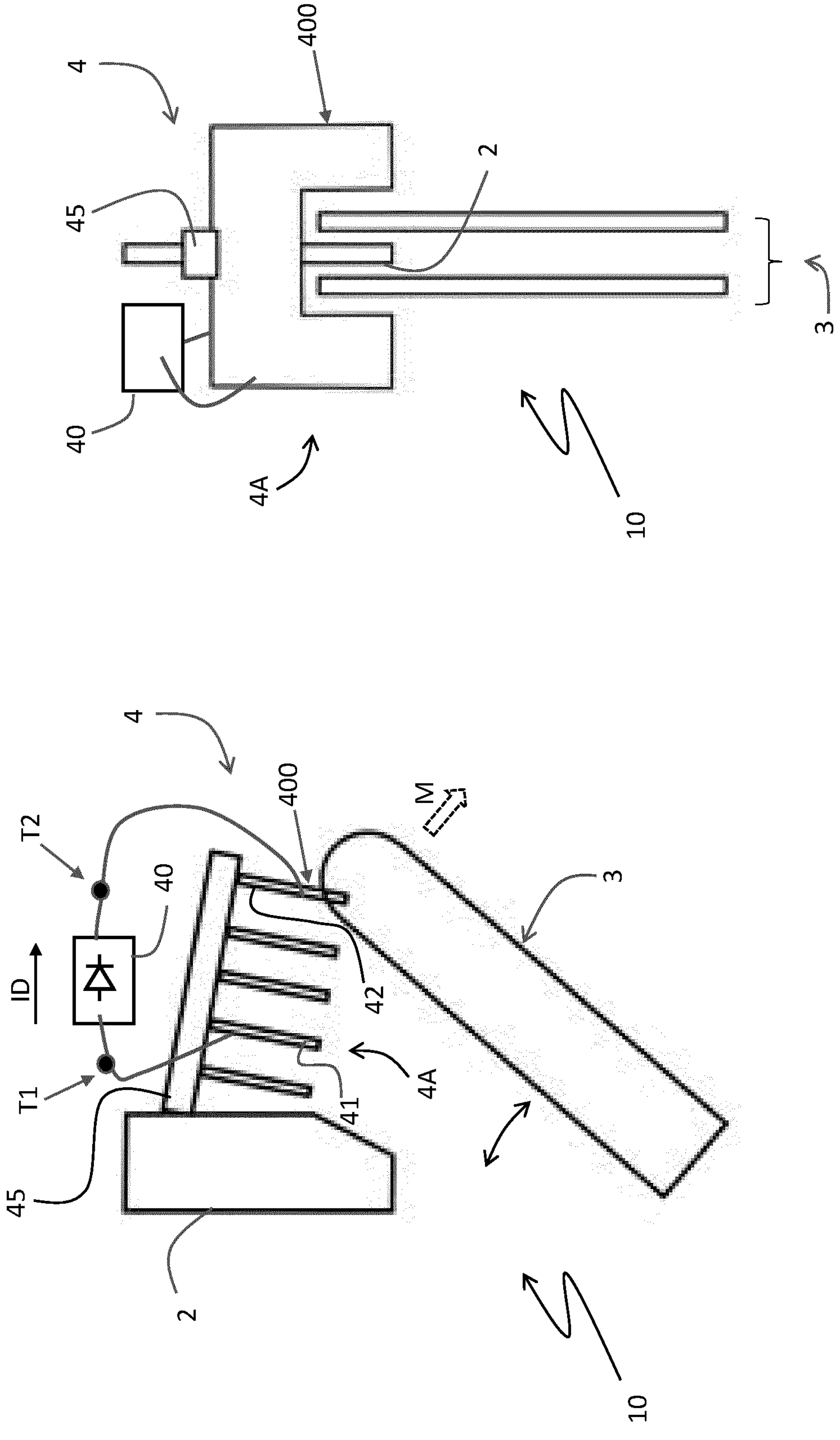


FIG. 3

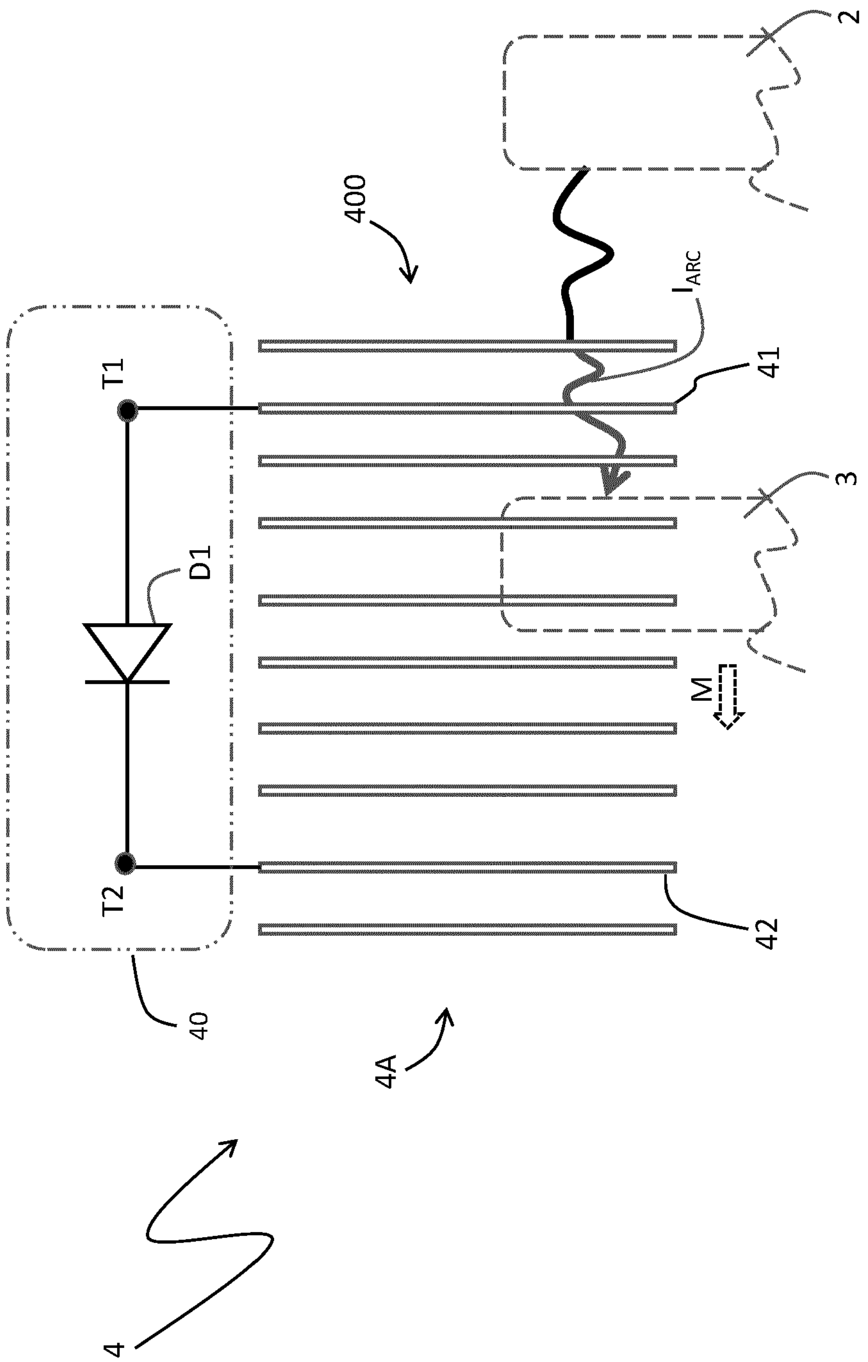


FIG. 4

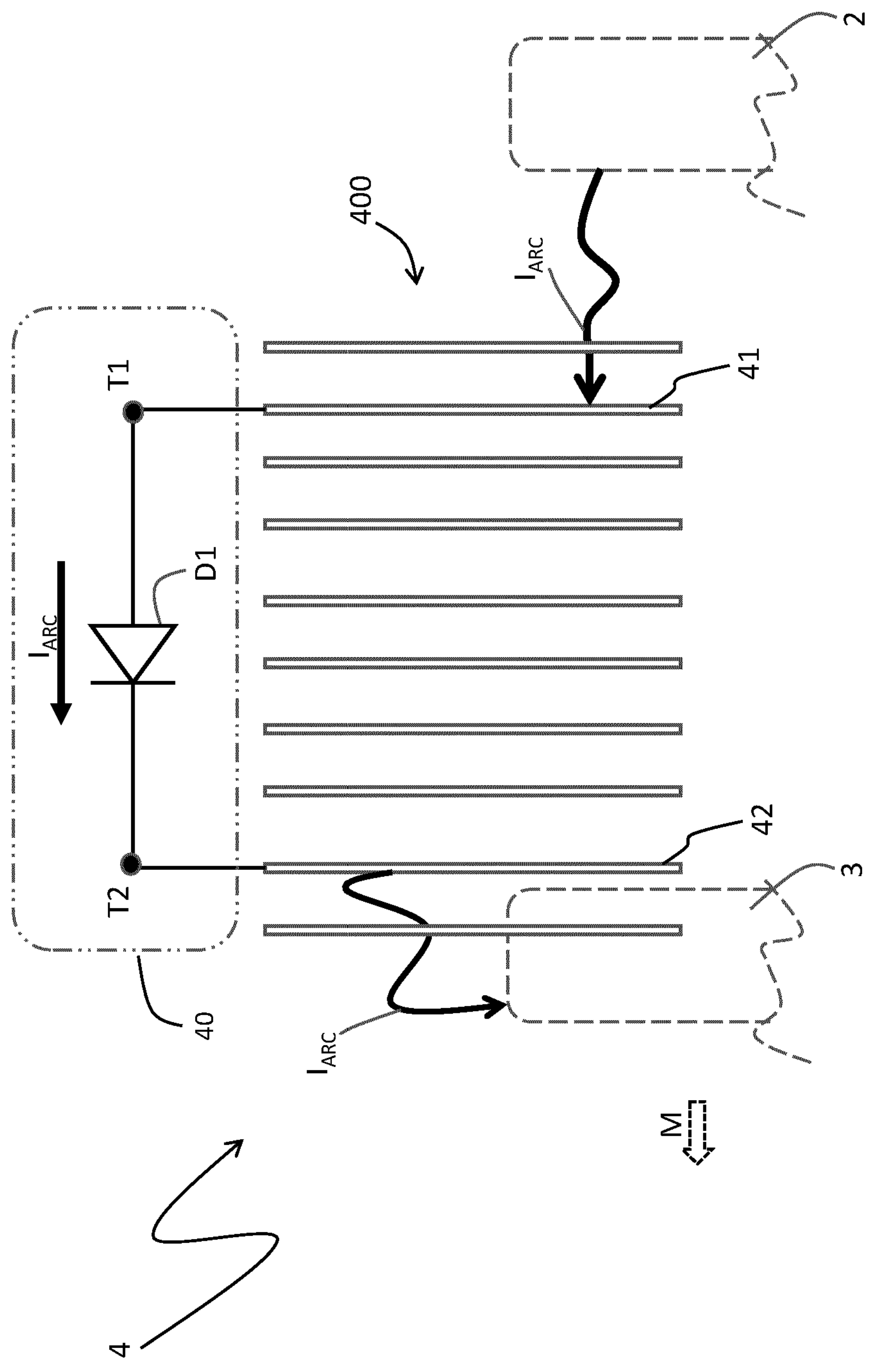


FIG. 5

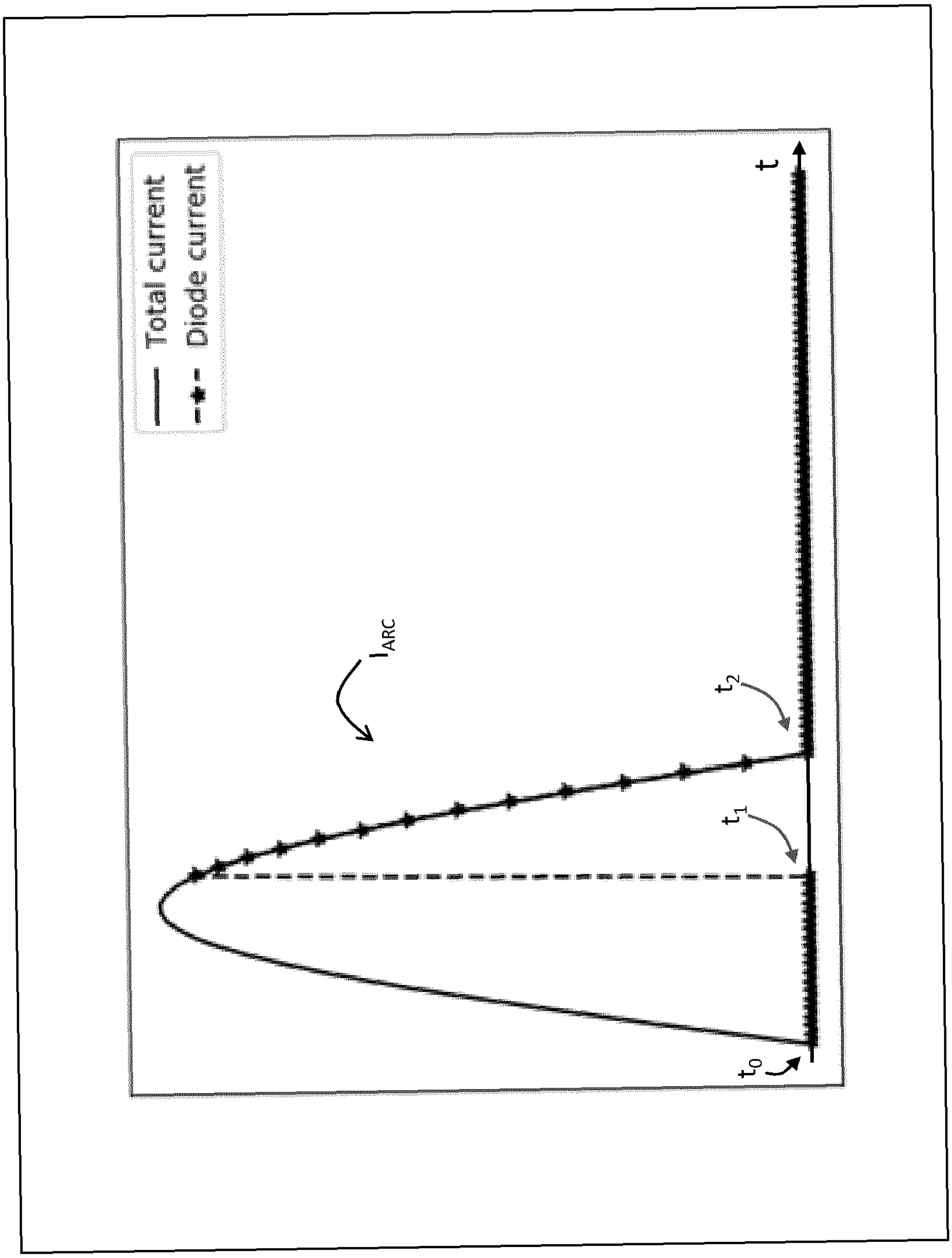
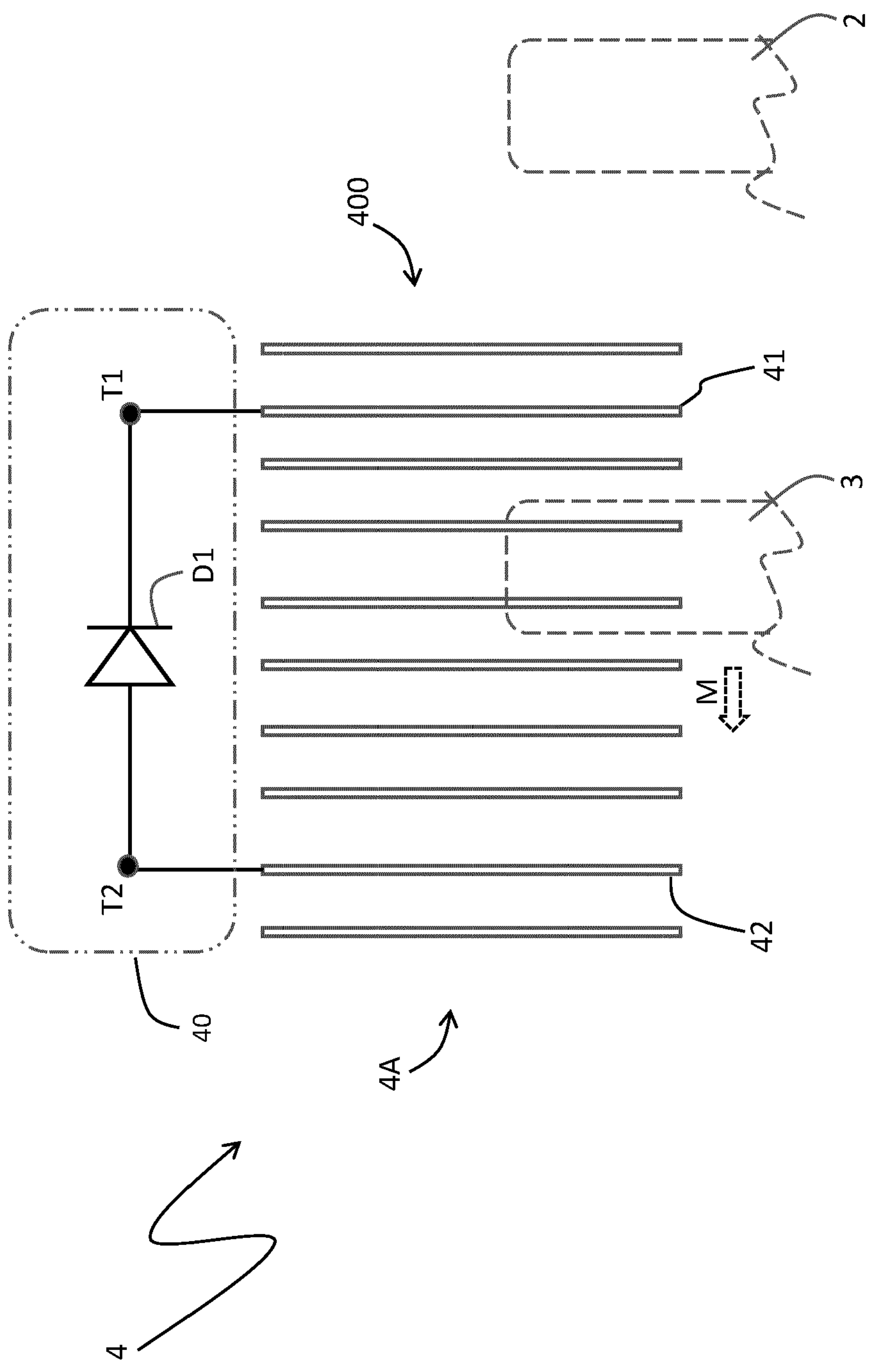


FIG. 6



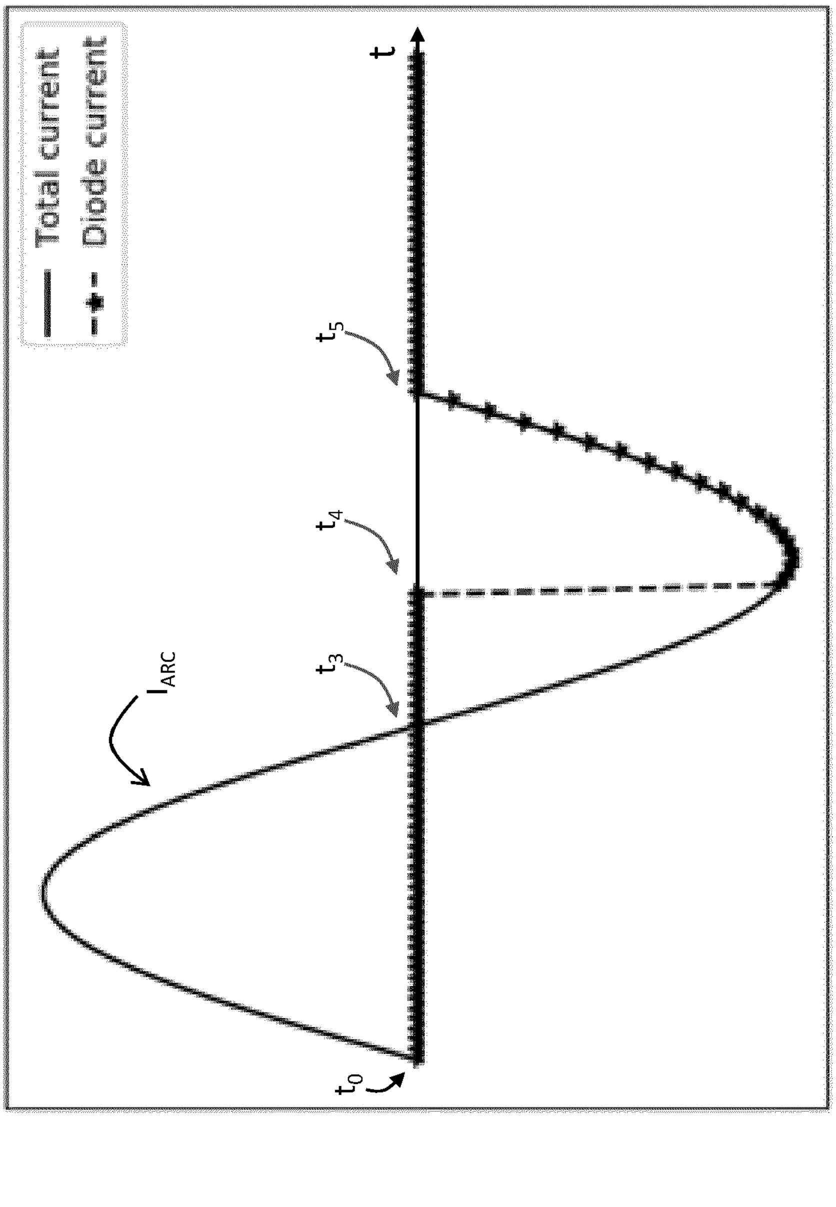


FIG. 7

FIG. 8

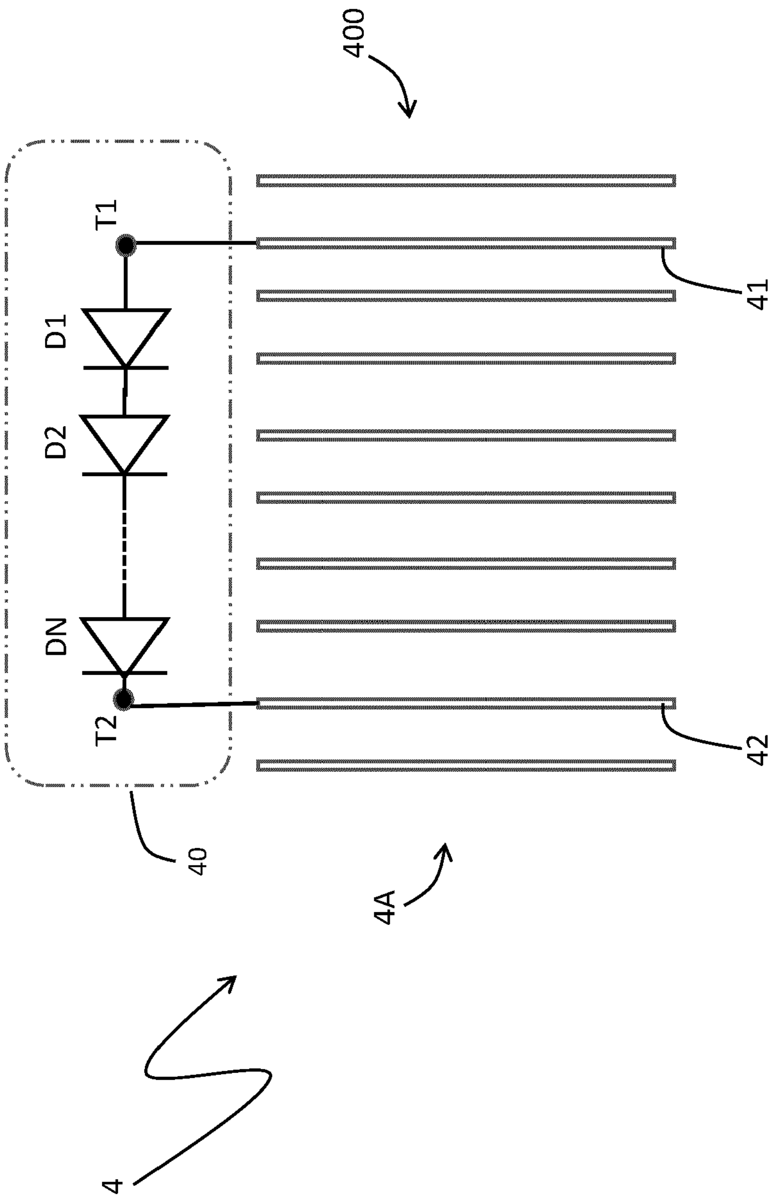


FIG. 9

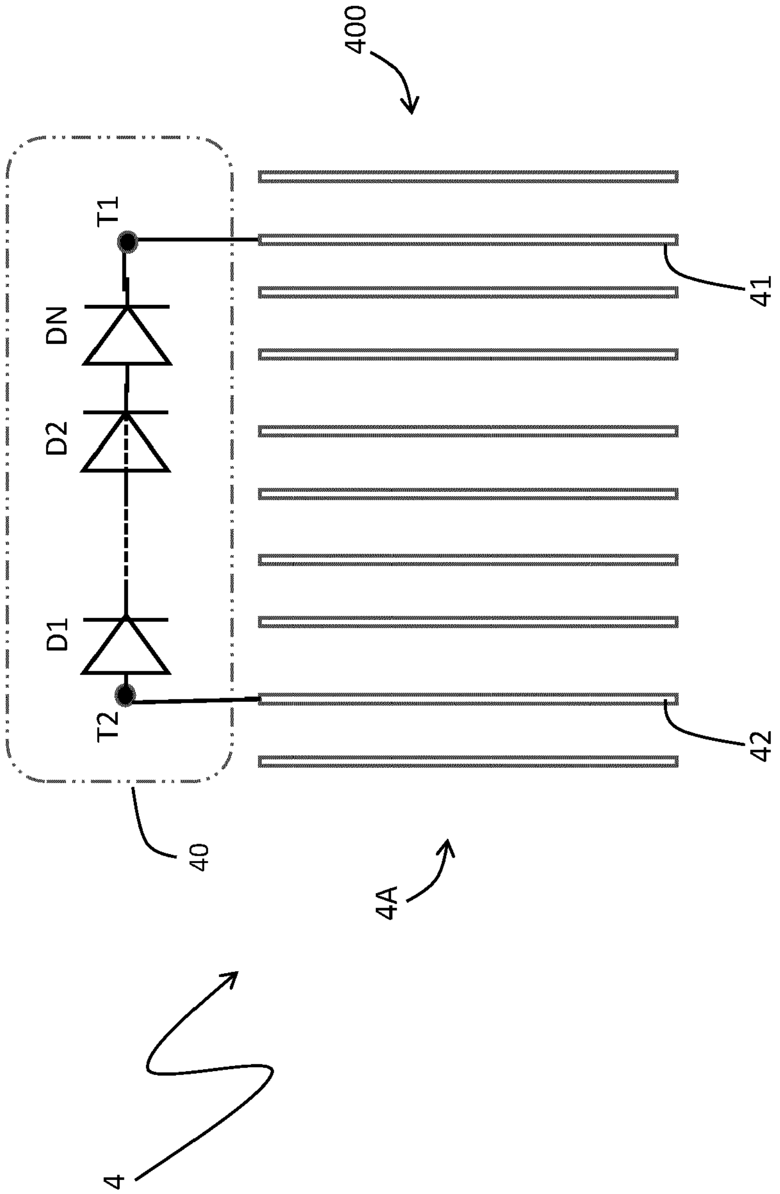
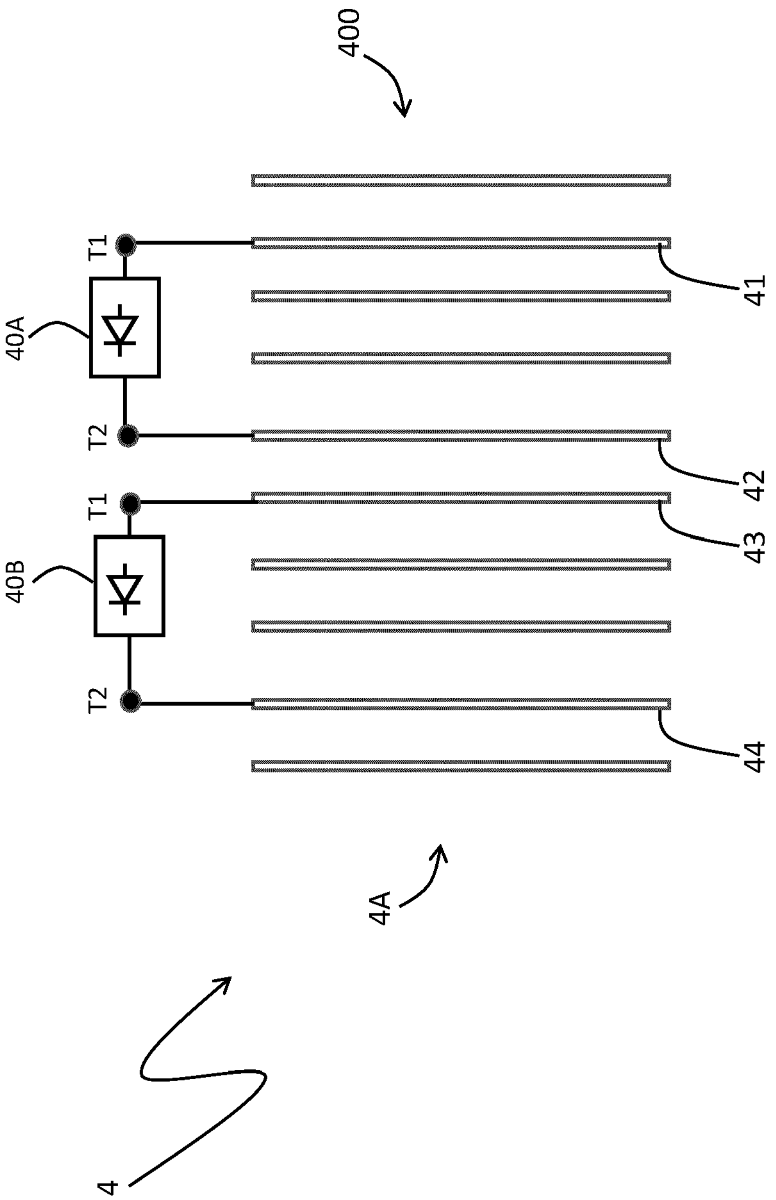


FIG. 10



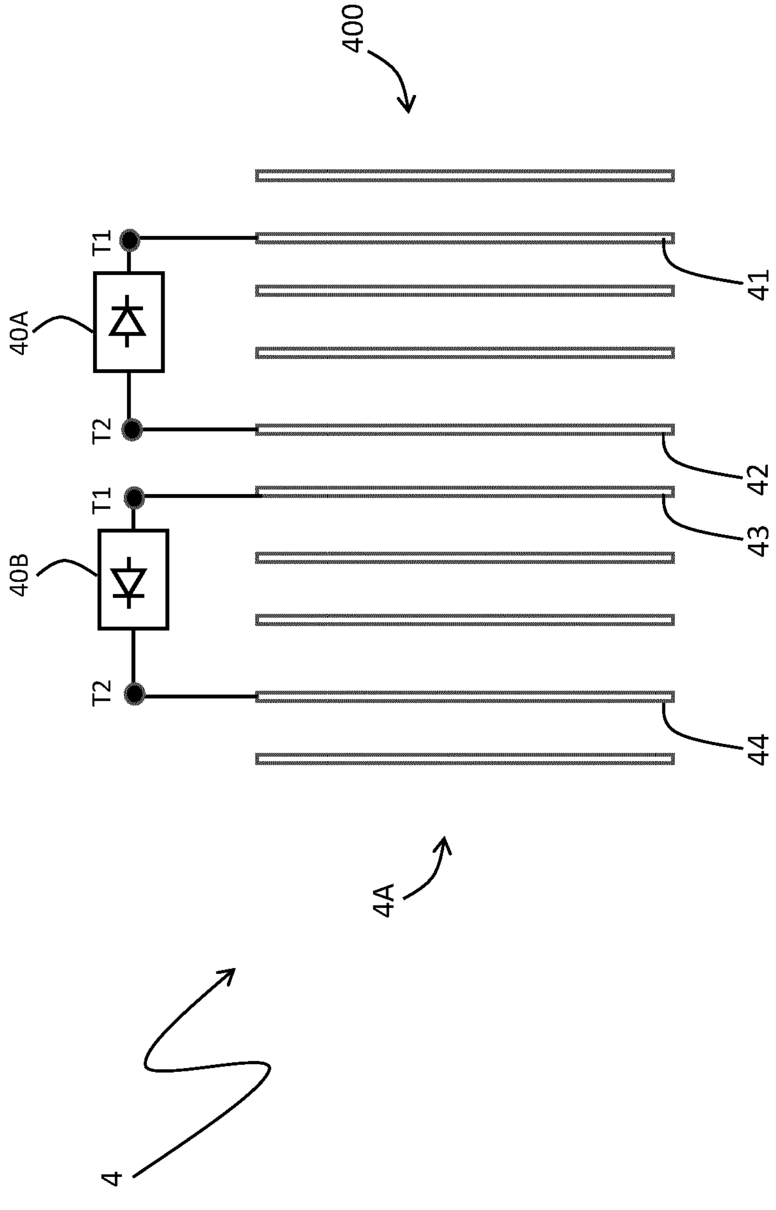


FIG. 11

FIG. 12

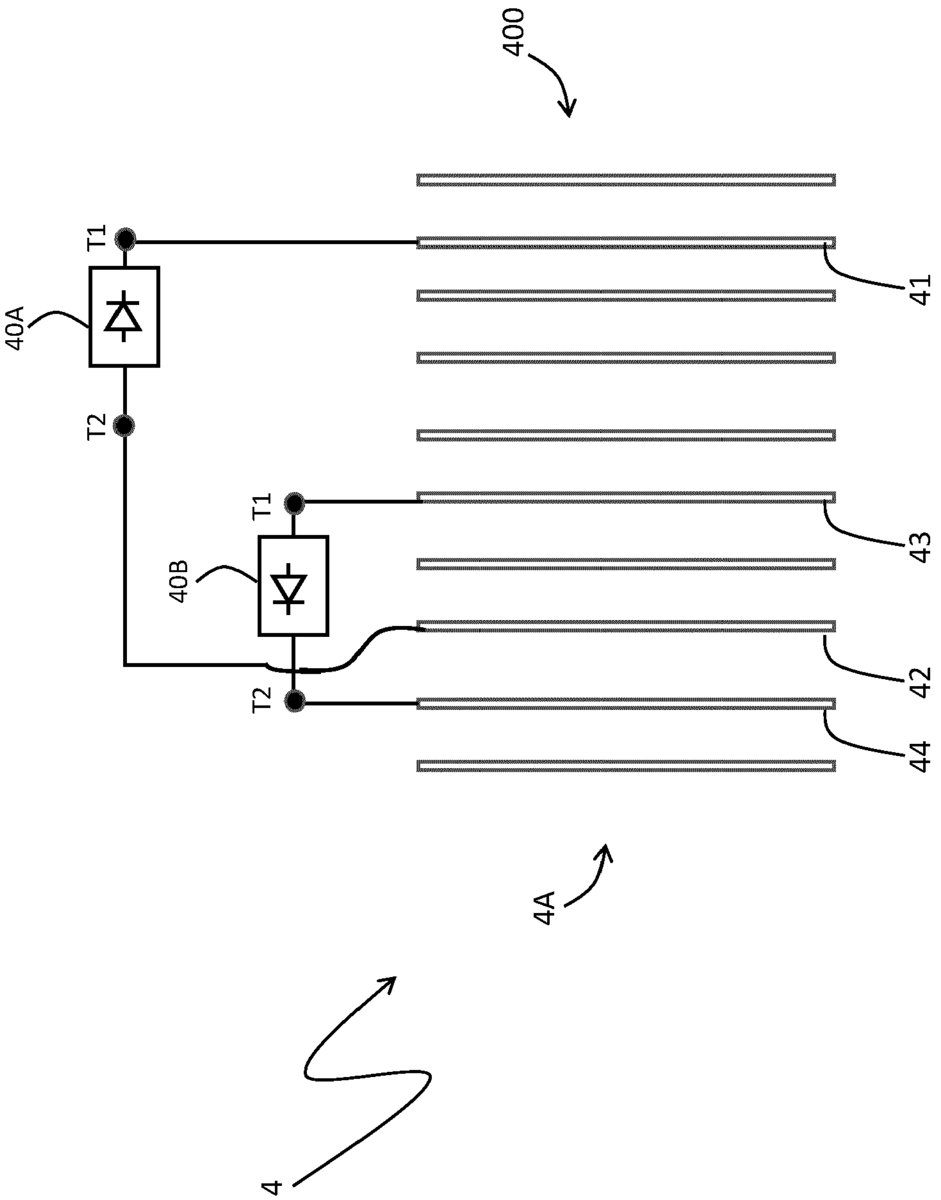


FIG. 13

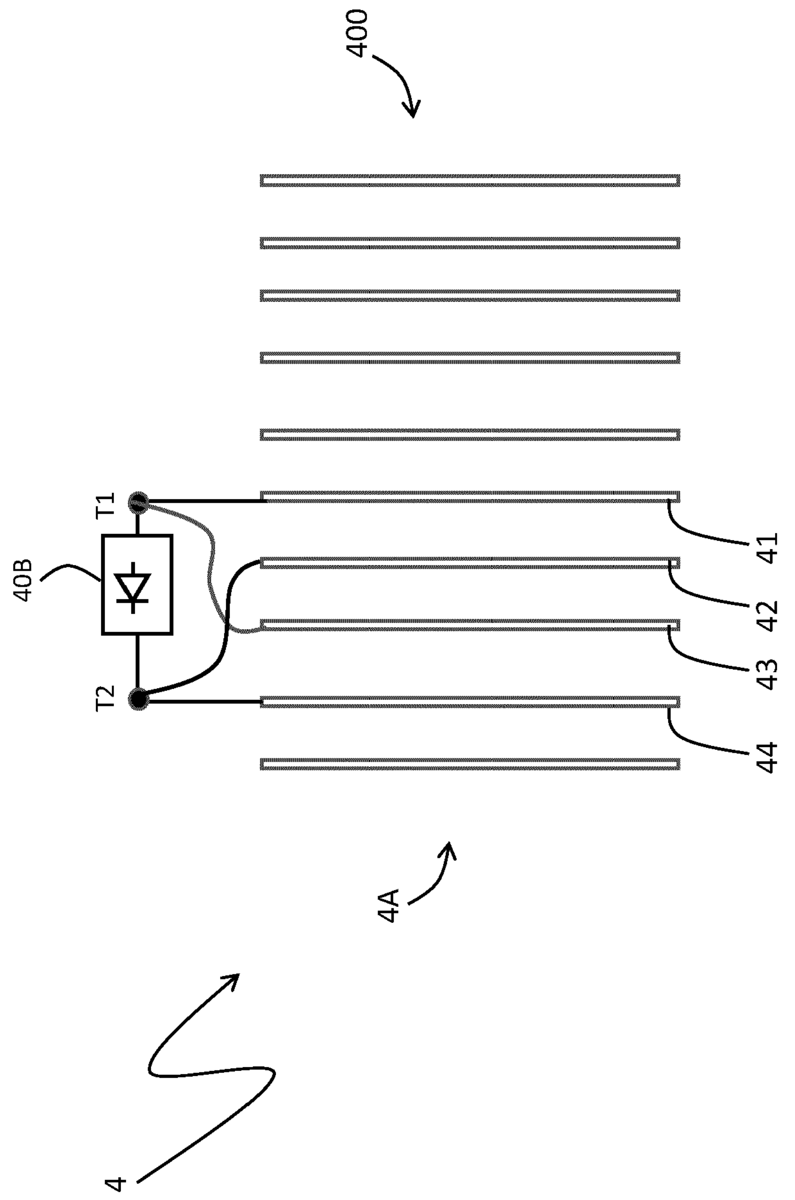
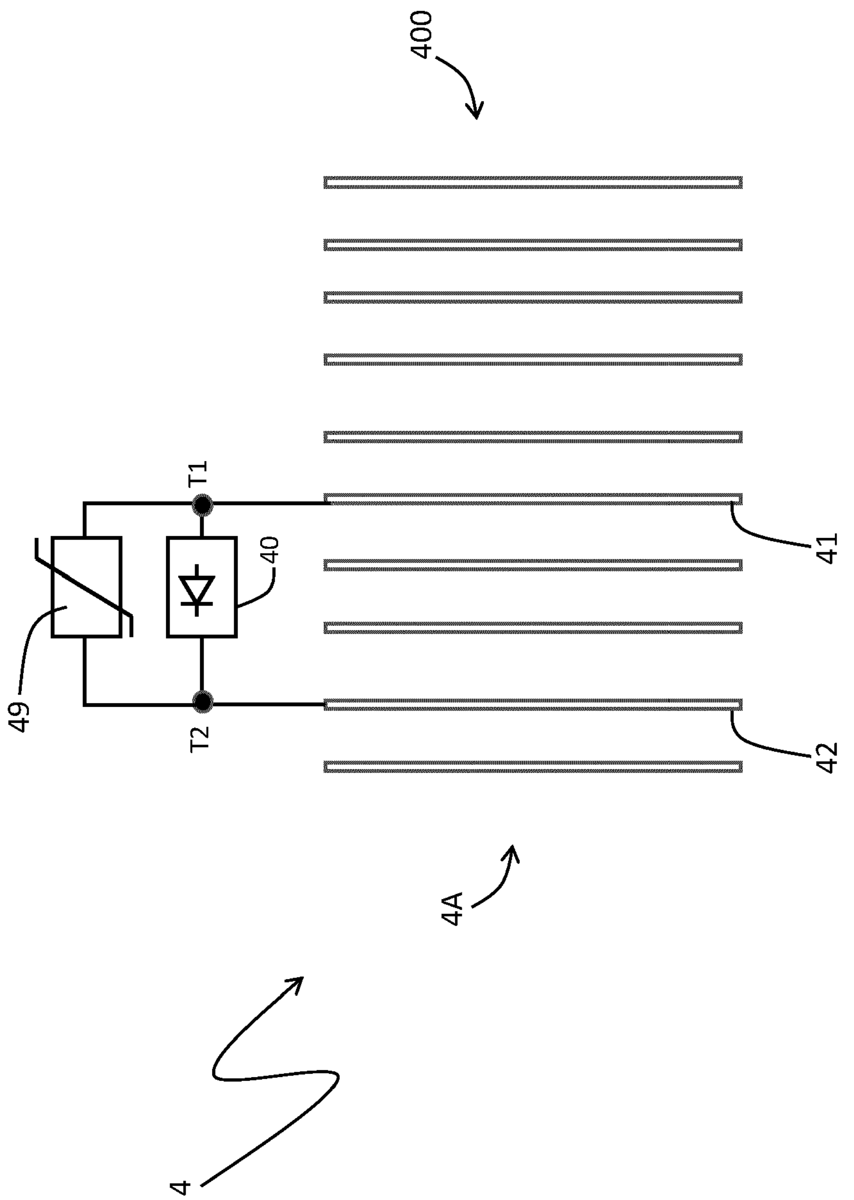


FIG. 14



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EUROPEAN SEARCH REPORT

Application Number
EP 20 17 4638

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Y	US 2017/358403 A1 (ZHOU XIN [US]) 14 December 2017 (2017-12-14) * figure 10 * -----	14	
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			H01H

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
Munich	8 October 2020	Simonini, Stefano

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For more details about this annex : see Official Journal of the European Patent Office, No. 12/82