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(54) **VOLTAGE LIMITING ENERGY ABSORBER WITH FAST THERMAL RECOVERY**

(57) An energy absorption device (1) for a circuit breaker, in particular a solid-state or a hybrid circuit breaker, includes an energy absorber (20) arranged within an enclosure (10) and a two-phase cooling arrangement. The two-phase cooling arrangement has one or more fluid distribution units (110) configured to direct a cooling fluid in a liquid state toward the energy absorber (20), the energy absorber (20) being cooled due to evaporation of the cooling fluid.

A circuit breaker, in particular solid-state or hybrid circuit breaker, includes one or more energy absorption devices (2, 3, 4).

A method for two-phase cooling of an energy absorber (20) of a circuit breaker, in particular a solid-state or hybrid circuit breaker, includes: after a switching operation of the circuit breaker, directing a cooling fluid in a liquid state toward the energy absorber (20). Thereby, the energy absorber (20) is cooled due to evaporation of the cooling fluid.

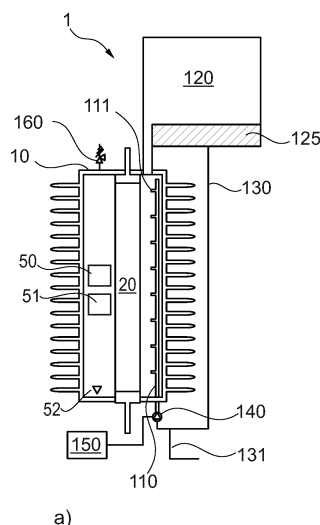


Fig. 2

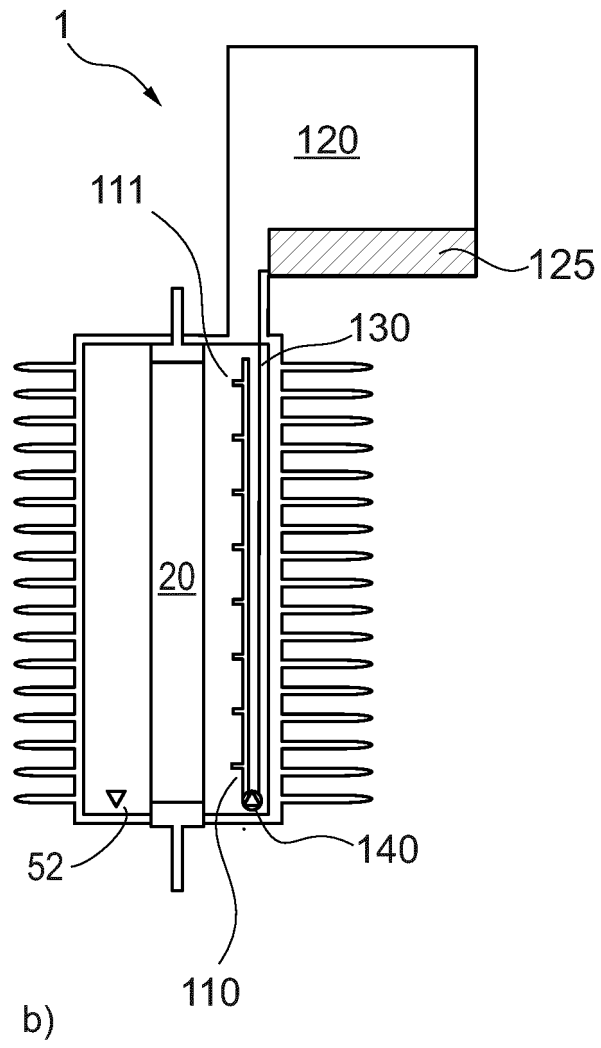


Fig. 2

Description

Field of the disclosure

[0001] The present disclosure relates to energy absorbers, more specifically varistors and even more specifically metal oxide varistors, as particularly used in connection with circuit breakers. The present disclosure further relates to a circuit breaker, in particular a direct current circuit breaker, and to a method for cooling energy absorbers.

Technical background:

[0002] Traditionally, mechanical circuit breakers (MCBs) have been utilized as protection devices in electrical networks. When a MCB is operated, the energy stored in the electrical network is dissipated in the electric arc that develops between the separated contacts. Due to improvements in semiconductor technology, solid-state circuit breakers (SSCBs) are becoming an alternative to MCBs. When a SSCB is operated, no electric arc develops. Therefore the energy stored in the electrical network has to be dissipated in another way. This is also true for hybrid circuit breakers (HCBs), which are a combination of SSCBs and MCBs.

[0003] For SSCBs and HCBs, energy absorbers including metal oxide varistors (MOVs) have been utilized to dissipate the energy in the form of heat. Operation (switching) of such SSCBs or HCBs leads to a strong temperature increase of the MOVs that imposes difficulties in the operation of the MOVs. In particular, a MOV may not be prepared for another switching operation for a specific time period after a switching operation which causes the need for back-up solutions that come along with additional costs and efforts.

[0004] In view thereof, it is desired to overcome at least some of the problems in the prior art.

Summary of the disclosure

[0005] In view of the above, an energy absorption device for a circuit breaker, a circuit breaker and a method for two-phase cooling of an energy absorber are provided.

[0006] The present disclosure provides an energy absorption device for a circuit breaker, in particular a solid-state or a hybrid direct current circuit breaker. The energy absorption device includes an energy absorber arranged within an enclosure and a two-phase cooling arrangement with one or more fluid distribution units. The one or more fluid distribution units are configured to direct a cooling fluid in a liquid state toward the energy absorber. The energy absorber is cooled due to evaporation of the cooling fluid.

[0007] The present disclosure further provides a circuit breaker, in particular solid-state or hybrid direct current circuit breaker. The circuit breaker includes one or more

energy absorption devices as described above.

[0008] The present disclosure further provides a method for two-phase cooling of an energy absorber of a circuit breaker, in particular a solid-state or hybrid direct current circuit breaker. The method includes: after a switching operation of the circuit breaker, directing a cooling fluid in a liquid state toward the energy absorber. Thereby, the energy absorber is cooled due to evaporation of the cooling fluid.

[0009] Traditionally, the MOVs are cooled by passive air cooling. Thermal recovery (cool-down) time of the MOVs after operation of the SSCBs or HCBs can be moderately shortened by the utilization of heat sinks positioned in proximity of the MOVs.

[0010] The shorter the thermal recovery time of the MOVs, the more switching events within a specified time period the MOVs can withstand without the temperature of the MOVs increasing above an acceptable limit.

[0011] An advantage is that by utilizing a two-phase cooling arrangement as described herein, the heat transfer can be increased greatly. Thereby, the thermal recovery of the energy absorber after a switching event is sped up so that the energy absorber has a short thermal recovery. This can make a reduction of the number of required energy absorbers, such as varistors possible. Furthermore, it may result in space savings. Cost savings due to a reduction of the required number of varistor blocks and the required space may be higher than the costs associated with the two-phase cooling. A net reduction of costs may therefore be possible.

[0012] Further advantages, features, aspects and details that can be combined with embodiments described herein are evident from the dependent claims, claim combinations, the description and the drawings.

Brief description of the Figures:

[0013] The details will be described in the following with reference to the figures, wherein

Fig. 1 is a schematic cross-sectional view of an energy absorption device according to an embodiment of the disclosure;

Fig. 2a is a schematic cross-sectional view of an energy absorption device according to another embodiment of the disclosure;

Fig. 2b is a schematic cross-sectional view of an energy absorption device according to another embodiment of the disclosure;

Fig. 3a is a schematic cross-sectional view of an energy absorption device according to another embodiment of the disclosure;

Fig. 3b is a schematic cross-sectional view of an energy absorption unit according to another embodi-

ment of the disclosure;

Fig. 3c is a schematic cross-sectional view of an energy absorption unit according to another embodiment of the disclosure;

Fig. 3d is a schematic cross-sectional view of the embodiment shown in Fig. 3c, viewed from above;

Fig. 4a is a schematic cross-sectional view of an energy absorption unit according to another embodiment of the disclosure;

Fig. 4b is a schematic cross-sectional view of an energy absorption unit according to another embodiment of the disclosure;

Fig. 4c is a schematic cross-sectional view of an energy absorption unit according to another embodiment of the disclosure;

Fig. 5a is a schematic cross-sectional view of a power electronics system including a hybrid circuit breaker with an energy absorption unit;

Fig. 5b is a schematic cross-sectional view of another embodiment of a power electronics system including a hybrid circuit breaker with an energy absorption unit.

Detailed description of the Figures and of embodiments:

[0014] Reference will now be made in detail to the various embodiments, one or more examples of which are illustrated in each figure. Each example is provided by way of explanation and is not meant as a limitation. For example, features illustrated or described as part of one embodiment can be used on or in conjunction with any other embodiment to yield yet a further embodiment. It is intended that the present disclosure includes such modifications and variations.

[0015] Within the following description of the drawings, the same reference numbers refer to the same or to similar components. Generally, only the differences with respect to the individual embodiments are described. Unless specified otherwise, the description of a part or aspect in one embodiment can be applied to a corresponding part or aspect in another embodiment as well.

[0016] Fig. 1 is a schematic cross-sectional view of an energy absorption device 1 for a circuit breaker, in particular a solid-state or direct current circuit breaker, according to an embodiment of the disclosure.

[0017] In the context of the present disclosure, an energy absorption device for a circuit breaker is in particular to be understood to be an energy absorption device which is configured to temporarily absorb the energy of an electrical network, the circuit breaker being a part of the electrical network.

[0018] The energy absorption device 1 includes an energy absorber 20 arranged within an enclosure 10 and a two-phase cooling arrangement with a fluid distribution unit 110. The fluid distribution unit 110 is configured to direct a cooling fluid in a liquid state toward the energy absorber 20, the energy absorber 20 being cooled due to evaporation of the cooling fluid. Evaporation includes in particular the process of heating the cooling fluid up prior to reaching its evaporation temperature. Thus, the energy absorber may also be cooled due to absorption of sensible heat by the cooling fluid.

[0019] Generally and not limited to any embodiment described herein, different options for the composition of the energy absorber are conceivable: The energy absorber may include a semiconductor. The semiconductor may for example be SiC. The energy absorber may particularly be a varistor. The energy absorber typically includes a metal oxide. The metal oxide may for example be ZnO. In embodiments, the energy absorber may be a metal oxide varistor.

[0020] Not limited to any embodiment, the two-phase cooling arrangement may include two or more fluid distribution units. The two or more fluid distribution units may be distributed over a plurality of different circumferential positions encircling the energy absorber. For example, the two-phase cooling arrangement may include three fluid distribution units spaced approximately 120° apart, encircling the energy absorber.

[0021] In embodiments, the two-phase cooling arrangement may include one or more fluid distribution units arranged at a distance of at least 1 cm and/or at most 50 cm from the energy absorber.

[0022] According to an aspect of the present disclosure, also a fluid distribution unit encircling the energy absorber at least partly or even fully may be provided. In embodiments, at least partly in this context can be understood as covering at least 270° of the circumference.

[0023] Fig. 2a is a schematic cross-sectional view of an energy absorption device 1 according to another embodiment of the disclosure. Only differences with respect to Fig. 1 are described.

[0024] Particularly in embodiments for outdoor application, the energy absorption device may include ribs formed from a dielectric material, in particular silicone, on an outer side of the enclosure. The ribs may extend in a horizontal direction as illustrated in Fig. 2a. The ribs may improve the dielectric properties of the energy absorption device. Thus, it may be possible to avoid flashovers, for example in humid conditions.

[0025] The two-phase cooling arrangement may further include a condenser 120.

[0026] The condenser 120 may be positioned in a vertical location that is above the enclosure 10. In particular embodiments, the condenser is provided on top of the enclosure.

[0027] The condenser 120 is typically connected to the enclosure 10 via a supply pipe. Not limited to this embodiment, the supply pipe may be configured for allowing

the evaporated cooling fluid to flow from the enclosure 10 to the condenser 120. The supply pipe may be integrated with the condenser 120. In embodiments wherein the condenser is provided directly on top of the enclosure the supply pipe may be omitted.

[0028] The condenser is provided so as to facilitate condensation of the cooling fluid that has evaporated within the enclosure. The condenser typically operates by providing a condensing surface that allows evaporated cooling fluid to decrease its temperature below its dew point on contact with the condensing surface. Cooling fluid that has evaporated within the enclosure is transported to the condenser by a flow pattern established within the enclosure. The condenser typically includes condenser walls that enclose a condenser volume. The condensing surface may be embodied by an inner surface of the condenser walls. Generally, the cooling fluid that has evaporated within the enclosure may also condense at least partly within the enclosure. In embodiments, a rate of condensation of the cooling fluid within the enclosure may be sufficient for operation of the two-phase cooling arrangement and a separate condenser may be omitted.

[0029] When cooling fluid condenses within the condenser volume, the pressure within the condenser volume is reduced. As a result, the pressure within the condenser may be lower than the pressure in the enclosure. The reduced pressure may facilitate the flow of further evaporated cooling fluid from the enclosure to the condenser. The further evaporated cooling fluid then typically also condenses within the condenser volume. Thereby, the reduced pressure within the condenser volume may be at least substantially maintained.

[0030] The condenser may be passively cooled. For this purpose, the condenser may be provided with cooling ribs. In some embodiments, the condenser may be actively cooled. Cooling can be done by an electric cooling unit (e.g. Peltier element) or by water cooling.

[0031] The two-phase cooling arrangement may further include a liquid storage volume 125. The liquid storage volume 125 may be configured to hold a cooling fluid in a liquid state. The cooling fluid held by the liquid storage volume 125 may be designated to be transported toward the energy absorber 20.

[0032] The liquid storage volume 125 may be positioned within the condenser 120. The term "within the condenser" in this context may be understood as "within the condenser volume".

[0033] The two-phase cooling arrangement may further include a fluid transportation unit 130, 140. The fluid transportation unit 130, 140 is typically configured to transport a cooling fluid toward the fluid distribution unit 110. In particular, the fluid transportation unit 130, 140 is configured to transport a cooling fluid from the liquid storage volume 125 to the fluid distribution unit 110.

[0034] The fluid transportation unit 130, 140 may include a pipe 130 and/or a pump 140. The pump 140 may be configured to facilitate the transport of the cooling fluid

to the fluid distribution unit 110, in particular the transport of cooling fluid from the liquid storage volume 125 to the fluid distribution unit 110. The pipe 130 may connect the liquid storage volume 125 to the pump 140. Thereby a transport of cooling fluid from the liquid storage volume 125 to the pump 140 is made possible. The pump 140 may be directly connected to the fluid distribution unit 110. Thereby, a transport of cooling fluid from the pump 140 to the fluid distribution unit 110 may be made possible. Alternatively, the transport of cooling fluid from the pump 140 to the fluid distribution unit 110 may be made possible by a further pipe (not shown in the figure). In proximity of the pump 140, the pipe 130 may include a connection 131 to fluid handling systems. The pump 140 may be positioned below the enclosure 10.

[0035] The fluid distribution unit 110 may be arranged within the enclosure 10. The fluid distribution unit 110 may include one or more nozzles 111. The one or more nozzles 111 may for example be spray nozzles. An exemplary embodiment of a spray nozzle is a PJ type low flow nozzle, manufactured by BETE Fog Nozzle, Inc.

[0036] The fluid distribution unit 110 may for example include one single nozzle 111. The one single nozzle 111 may be located in a horizontal direction adjacent to an upper region of the energy absorber 20. Typically, the upper region of the energy absorber can be understood as the region being between 80 and 100% of the energy absorber's length as measured from the energy absorber's bottom.

[0037] By having only one nozzle 111, a fluid distribution unit 110 with an especially simple structure may be realized. The nozzle 111 may be configured to direct the cooling fluid to the upper region of the energy absorber 20.

[0038] Cooling fluid that comes into contact with the energy absorber 20 in an upper region of the energy absorber 20 may flow down on an outside wall of the energy absorber 20 due to gravitation. This way a large part of the surface area of the energy absorber 20, for example more than 65% or more than 85% of the total surface area of the energy absorber 20 may come into contact with the cooling fluid. In embodiments, the whole surface area of the energy absorber comes into contact with the cooling fluid.

[0039] In embodiments, the fluid distribution unit may include two nozzles. A first nozzle may be positioned in a horizontal direction adjacent to an upper region of the energy absorber. A second nozzle may be positioned in a horizontal direction adjacent to a middle region of the energy absorber. The middle region of the energy absorber may be located approximately halfway between an upper region of the energy absorber and a lower region of the energy absorber. "Halfway" in this context can be understood as a region of between 40 and 60% of the energy absorber's length as measured from the energy absorber's bottom.

[0040] Compared with embodiments wherein the fluid distribution unit includes only one nozzle, embodiments

wherein the fluid distribution includes two nozzles may have the advantage of a more homogeneous distribution of the cooling fluid on the surface of the energy absorber.

[0041] The fluid distribution unit may also include for example five or more nozzles to ensure an even more homogeneous distribution of the cooling fluid on the surface of the energy absorber.

[0042] The energy absorption device 1 may further include a temperature sensor 50. The temperature sensor 50 may be arranged within the enclosure.

[0043] In embodiments, the temperature sensor may be arranged on the energy absorber.

[0044] The energy absorption device may include a pressure sensor 51. The pressure sensor may be arranged within the enclosure 10. The pressure sensor 51 may be configured to measure a pressure within the enclosure 10.

[0045] The energy absorption device 1 may further include a cooling liquid level sensor 52. The cooling liquid level sensor 52 may be arranged within the enclosure 10. The cooling liquid level sensor 52 may be configured to sense if there is a liquid, in particular cooling fluid in a liquid phase, collected up to a particular height within the enclosure 10. In embodiments, the cooling liquid level sensor 52 is configured to sense the height up to which liquid, in particular cooling fluid in a liquid phase, has been collected within the enclosure 10. The cooling liquid level sensor may be embodied as a humidity sensor.

[0046] The energy absorption device 1 may further include a pressure relief valve 160. The pressure relief valve 160 may be arranged on an outer side of a wall of the enclosure 10. The pressure relief valve 160 may be configured to enable a reduction of a pressure within the enclosure 10. The pressure relief valve 160 may enable an automatic reduction of a pressure within the enclosure when the pressure exceeds a critical threshold. Thereby, a protection against explosions, particularly explosions due to rapid heating of cooling fluid that has accumulated within the enclosure in a liquid state, may be provided. A safe operation of the energy absorption device may be ensured. Other arrangements for protection against explosions may be provided. The enclosure may include or be encompassed by a security enhancing material. An explosion-proof enclosure can be provided.

[0047] The two-phase cooling arrangement may further include a control unit 150. The control unit 150 may be configured to activate the fluid transportation unit 130, 140 when a switching event occurs in the circuit breaker. For receiving signals from the circuit breaker, the control unit may be connected to the circuit breaker. The control unit may for example be connected to a current sensor arranged in the circuit breaker. In the context of the present disclosure, a switching event occurring in a circuit breaker is in particular to be understood to mean that an electrical connection is interrupted by the circuit breaker. In embodiments, to activate the fluid transportation unit 130, 140 is in particular to be understood to mean to activate the pump 140. Thus, a two-phase cooling ar-

angement may be provided that is configured to start two-phase cooling of the energy absorber 20 after a switching event occurs in the circuit breaker.

[0048] In embodiments, the control unit 150 may be configured to receive signals from one or both of a temperature sensor 50, a pressure sensor 51 and a cooling liquid level sensor 52 and, depending on the signals received, control the fluid transportation unit 130, 140 so as to change the flow rate. The control unit 150 may also be configured to control the fluid transportation unit 130, 140 so as to change the flow rate depending on the amount of time that has elapsed since the switching event of the circuit breaker. To control the fluid transportation unit 130, 140 so as to change the flow rate is in particular to be understood to mean to change the flow rate of the pump 140.

[0049] For example, during two-phase cooling after a switching event in the circuit breaker, the signal received by the control unit from the cooling liquid level sensor may indicate that there is a buildup of cooling fluid in a liquid phase within the enclosure. The control unit may then control the fluid transportation unit so as to reduce its flow rate so as to prevent a further buildup of cooling fluid in a liquid phase within the enclosure and particularly to promote a complete evaporation of the cooling fluid already present within the enclosure.

[0050] As another example, during two-phase cooling after a switching event in the circuit breaker, the signal received by the control unit from the temperature sensor may indicate that the temperature has gone below a certain threshold. The control unit may then control the fluid transportation unit so as to reduce its flow rate in order to prevent a buildup of cooling fluid in a liquid phase within the enclosure. The control unit may further be configured to stop the two-phase cooling once another temperature threshold value is underrun.

[0051] The energy absorption device may further include electrical connectors for connecting the energy absorber to an electrical network.

[0052] Fig. 2b shows another embodiment of an energy absorption device 1. Only differences with respect to Fig. 2a are described. The pump 140 of the fluid transportation unit 130, 140 may be arranged within the enclosure 10. The pipe 130 of the fluid transportation unit 130, 140 may be arranged within the enclosure 10. In particular, the fluid transportation unit 130, 140 is at least substantially or even completely arranged within the enclosure 10. This arrangement allows the transport of cooling fluid in a liquid phase from the liquid storage volume 125 to the fluid distribution unit 110 to take place at least substantially or even entirely within the enclosure 10.

[0053] Fig. 3a shows another embodiment of an energy absorption device 1. Only differences with respect to Fig. 2a are described. The energy absorption device 1 may include a first condenser 120 and a second condenser 121. The second condenser 121 may be positioned above the first condenser 120. The one or more condensers 120, 121 as provided in the present disclo-

sure may be positioned besides the enclosure 10. Each of the condensers 120, 121 may be connected to the enclosure 10 via a separate supply pipe. The supply pipes of the condensers 120, 121 may each be integrated with the respective condenser 120, 121. The supply pipes may extend in a horizontal direction. Thus, space may be saved. Multiple passageways for a transfer of evaporated cooling fluid out of the enclosure may be realized. This may lead to an increased flow rate. As a result, the cooling rate may be increased.

[0054] The energy absorption device 1 may further include a first pipe 130 and a second pipe 132. The first pipe 130 may connect the first condenser 120 to the pump 140. Thus, a transfer of cooling fluid that has condensed in the first condenser 120 to the pump 140 may be enabled. The second pipe 132 may connect the first condenser 120 to the second condenser 121. Thus, a transfer of cooling fluid that has condensed in the second condenser 121 to the first condenser 120 may be enabled.

[0055] Fig. 3b shows another embodiment of an energy absorption device 1. Only differences with respect to Fig. 2a are described.

[0056] The energy absorption device 1 may include a condenser 120 that is positioned directly on top of the enclosure 10. In a region where the condenser 120 is connected to the enclosure 10, an area that is available for a flow of a cooling fluid may be at least as large as 50% of an area of a horizontal cross-section of the enclosure 10. In embodiments, the flow path between the enclosure 10 and the condenser 120 may be at least substantially unobstructed. A particularly high flow rate of cooling fluid from the enclosure 10 to the condenser 120 may be realized. Thus, a particularly high cooling rate of the energy absorber 20 may be achieved.

[0057] Fig. 3c shows another embodiment of an energy absorption device 1. Only differences with respect to Fig. 2a are described. In this embodiment, the enclosure 10 may be at least partly embodied as a condenser 120.

[0058] The enclosure being at least partly embodied as a condenser is in particular to be understood in that the energy absorber is enclosed by a structure that is configured to facilitate condensation of an evaporated cooling fluid. Thus, a separate condenser may be omitted. As a result, space may additionally be saved. In embodiments, the enclosure may include a material with a high thermal conductivity, for example copper or aluminum.

[0059] The enclosure 10 may further include a first bushing 160 and a second bushing 161. The bushings 160, 161 may be configured to electrically insulate the condenser 120 from the energy absorber 20. The first bushing 160 may be arranged in an upper region of the condenser 120. In particular, the first bushing 160 may form an upper wall of the enclosure 10. The second bushing 161 may be arranged in a lower region of the condenser 120. In particular, the second bushing 161 may form a lower wall of the enclosure 120.

[0060] Fig. 3d is a schematic cross-sectional view of

the embodiment shown in Fig. 3c, viewed from above. Two, three, four, five or even more fluid distribution units 110 may be arranged within the enclosure 10. In the specific example of Fig. 3d, three fluid distribution units 110 are depicted. The three fluid distribution units 110 may be distributed over different circumferential positions encircling the energy absorber 20, in particular, they may be arranged at equal distances around the energy absorber.

[0061] The condenser 120 may have cooling fins 126. This may increase the heat dissipation from the condenser 120. The cooling fins 126 may extend in a vertical direction. The cooling fins 126 may be at least partly hollow. In embodiments, the hollow cooling fins 126 may be configured to allow for access of evaporated cooling fluid into the hollow parts of the cooling fins 126 from the inside of the condenser. Thus, an area provided to facilitate condensation of the evaporated cooling fluid may be increased.

[0062] Fig. 4a shows another embodiment of an energy absorption device 1. Only differences with respect to Fig. 2a are described. The fluid distribution unit 110 may be embodied as a liquid release unit. The liquid release unit may be configured to be switchable between a holding state and a releasing state.

[0063] The liquid release unit may be configured to hold back a cooling fluid stored in the liquid storage volume 125, when the liquid release unit is in the holding state. The liquid release unit may further be configured to release the cooling fluid stored in the liquid storage volume 125, when the liquid release unit is in the releasing state. The release of the cooling fluid allows the cooling fluid to flow onto the energy absorber 20 due to gravitation. Particularly, no pump is required to transport the cooling fluid from the liquid storage volume 125 to the liquid release unit. The liquid release unit may be arranged within the condenser 120.

[0064] The energy absorption device 1 may include a liquid return unit 136, 145. The liquid return unit 136, 145 may be configured to return cooling fluid, particularly in a liquid phase, from the enclosure 10 to the liquid storage volume 125. The liquid return unit 136, 145 may thus return cooling fluid that did not evaporate within the enclosure to the liquid storage volume 125. Furthermore, the liquid return unit 136, 145 may thus return cooling fluid that condensed within the enclosure 10 to the liquid storage volume 125.

[0065] The liquid return unit 135, 145 may include a pump 145 and/or a pipe 136. The pump 145 may be positioned in a lower part of the enclosure 10. The pump 145 may have an inlet provided for access of cooling fluid, particularly in a liquid phase, into the pump 145. The pipe 136 may connect the pump 145 to the liquid storage volume. The pipe 136 may be positioned at least partly within the enclosure 10. In embodiments, the pipe 136 may be positioned at least substantially outside the enclosure 10.

[0066] The two-phase cooling arrangement may fur-

ther include a control unit 150. The control unit 150 may be configured for switching the fluid distribution unit 110 embodied as a liquid release unit. Switching the liquid release unit is in particular to be understood to mean inducing the liquid release unit to switch from the holding state to the releasing state. The control unit 150 may be configured to switch the liquid release unit when a switching event occurs in the circuit breaker. Thus, a two-phase cooling arrangement may be provided that is configured to ignite two-phase cooling of the energy absorber 20 after a switching event occurs in the circuit breaker.

[0067] In embodiments, the control unit may be configured to receive signals from any of the circuit breaker, a temperature sensor, a pressure sensor and a cooling liquid level sensor and, depending on the signals received, control the liquid release unit so as to change the flow rate. The control unit may also be configured to control the liquid release unit so as to change the flow rate depending on the amount of time that has elapsed since the switching event of the circuit breaker. To control the liquid release unit so as to change the flow rate is in particular to be understood to mean to switch the liquid release unit.

[0068] For example, during two-phase cooling after a switching event in the circuit breaker, the signal received by the control unit from the cooling liquid level sensor may indicate that there is a buildup of cooling fluid in a liquid phase within the enclosure. The control unit may then control the liquid release unit so as to reduce its flow rate so as to prevent a further buildup of cooling fluid in a liquid phase within the enclosure and particularly to promote a complete evaporation of the cooling fluid already present within the enclosure.

[0069] As another example, during two-phase cooling after a switching event in the circuit breaker, the signal received by the control unit from the temperature sensor may indicate that the temperature has gone below a certain threshold. The control unit may then control the liquid release unit so as to reduce its flow rate in order to prevent a buildup of cooling fluid in a liquid phase within the enclosure.

[0070] Fig. 4b shows another embodiment of an energy absorption device 1. Only differences with respect to Fig. 4a are described. The two-phase cooling arrangement may be configured to work passively. The liquid return unit may be omitted. A return of cooling fluid in a liquid phase that has accumulated within the enclosure to the liquid storage volume may be realized by evaporation of the cooling fluid. The evaporation may be caused by a heat transfer from the energy absorber to the accumulated cooling fluid.

[0071] Fig. 4c shows another embodiment of an energy absorption device 1. Only differences with respect to Fig. 1a are described.

[0072] The energy absorption device 1 may include a first energy absorber unit 2 and a second energy absorber unit 3. The first energy absorber unit 2 and the second energy absorber unit 3 may each be structurally at least

substantially identical to the energy absorption device 1 disclosed in Fig. 2a and the description of Fig. 2a.

[0073] The energy absorption device 1 may further include a fluid reservoir 170. The fluid reservoir may embody a shared liquid storage volume 125 for the first energy absorber unit 2 and the second energy absorber unit 3. The condenser 120 of the first energy absorber unit 2 may be connected to the fluid reservoir 170 via a first pipe 130. The condenser 121 of the second energy absorber unit 3 may be connected to the first pipe 130 via a second pipe 132.

[0074] The first energy absorber unit 2 and the second energy absorber unit 3 may further have a shared fluid transportation unit 133, 140, 141, 134, 135. The fluid transportation unit 133, 140, 141, 134, 135 may be configured to transport a cooling fluid toward the fluid distribution unit 110 of the first energy absorber unit 2 and to the fluid distribution unit 115 of the second energy absorber unit 3. In particular, the fluid transportation unit 133, 140, 141, 134, 135 may be configured to transport a cooling fluid from the liquid storage volume 125 to the fluid distribution units 110, 115.

[0075] The fluid transportation unit 133, 140, 141, 134, 135 may include a pipe 133 connecting the liquid storage volume 125 to a first pump 140. The fluid transportation unit 133, 140, 141, 134, 135 may further include a first distribution pipe 134 connecting the first pump 140 to the fluid distribution unit 110 of the first energy absorber unit 2. The fluid transportation unit may further include a second distribution pipe 135 connecting the first distribution pipe 134 to the fluid distribution unit 115 of the second energy absorber unit 3.

[0076] In embodiments, the pipes of the energy absorption device may include separation valves (not shown) configured to allow selectively closing down access to and from the respective two-phase cooling arrangement of each the first energy absorber unit and the second energy absorber unit. Thus, the safety of the energy absorption device may be increased. Further, a simplification of maintenance operations may be achieved.

[0077] In embodiments, the energy absorption device may include a control unit configured to operate separation valves so as to close down access to and from the two-phase cooling arrangement of an energy absorber unit in which a pressure relieve valve has been activated due to a critical pressure value. Thus, the safety of the energy absorption device may be further increased.

[0078] The fluid transportation unit 133, 140, 141, 134, 135 may also include a further pump 141 connected in parallel to the pump 140. Through this redundancy, the dependability of the energy absorption device may be enhanced.

[0079] Fig. 5a is a schematic view of a power electronics system including a hybrid circuit breaker with an energy absorption device 1. The power electronics system may include a first semiconductor switch 200, a second semiconductor switch 201 and a third semiconductor switch 202. The energy absorption device 1 may include

a first energy absorber unit 2, a second energy absorber unit 3 and a third energy absorber unit 4. The first energy absorber unit 2 may include an enclosure 10 that contains an energy absorber 20. The first energy absorber unit 2 may further include a condenser 120 positioned in a vertical location that is above the enclosure 10.

[0080] The energy absorber 20 may include five energy absorption blocks 30. The energy absorber 20 further may include one or more heat sinks (not shown). For example, one heat sink may be positioned between every pair of neighboring energy absorption blocks 30. Each of the one or more heat sinks may include aluminum or copper. The heat sinks may additionally reduce the time it takes for an energy absorber to cool down after having absorbed a certain amount of energy.

[0081] The second energy absorber unit 3 and the third energy absorber unit 4 may each be structurally at least substantially identical to the first energy absorber unit 2.

[0082] The energy absorbers of the first energy absorber unit 2, the second energy absorber unit 3 and the third energy absorber unit 4 may be connected electrically in series. The energy absorber 20 of the first energy absorber unit 2 may be connected electrically in parallel to the first semiconductor switch 200. The energy absorber of the second energy absorber unit 3 may be connected electrically in parallel to the second semiconductor switch 201. The energy absorber of the third energy absorber unit 4 may be connected electrically in parallel to the third semiconductor switch 202.

[0083] The hybrid circuit breaker may include a mechanical switch 300 and a commutation switch 301 connected electrically in series.

[0084] Fig. 5b is a schematic view of another embodiment of a power electronics system including a hybrid circuit breaker with an energy absorption device 1. Only differences with respect to Fig. 5a are described. The condensers 120 of the first energy absorber unit 2, the second energy absorber unit 3 and the third energy absorber unit 4 may be connected in series via pipes. The condensers 120 are connected to a centralized cooling tower 160.

[0085] In the following, further possible aspects, embodiments and variations according to the disclosure are described. Each of these aspects or embodiments can be implemented in combination with any other embodiment, and/or in combination with any other aspect described herein.

[0086] The energy absorption device can be a device configured to temporarily absorb an energy contained in an electrical network, in particular when the circuit breaker is operated. The energy absorption device may be configured to convert the energy into heat energy.

[0087] The circuit breaker may be a solid-state circuit breaker or a hybrid circuit breaker. The solid state circuit breaker can be a circuit breaker including a solid-state switch. The hybrid circuit breaker can be a circuit breaker including both a solid-state switch and a mechanical switch. The mechanical switch may be a dielectric with-

stand switch or a commutator switch. In embodiments, the hybrid circuit breaker may be a circuit breaker including both a solid-state switch and a combination of a mechanical switch with a power electronics based commutation switch.

[0088] The solid-state circuit breaker may have a galvanic isolation switch connected in series with the solid-state switch. The hybrid circuit breaker may have a galvanic isolation switch connected in series with any of: the solid-state switch, the mechanical switch and the power electronics based commutation switch.

[0089] In particular, the circuit breaker may be a high voltage direct current (HVDC) hybrid circuit breaker. The energy absorption device may include one or more energy absorbers. At least one of the one or more energy absorbers may include a resistor. In particular, each energy absorber may include a resistor. The resistor may have an electrical conductivity below 10^6 S/m , preferably below 10^4 S/m and more preferably below 10^2 S/m .

[0090] In embodiments, at least one of the one or more energy absorbers may include a semiconductor. In particular, each energy absorber may include a semiconductor. The semiconductor may for example be SiC. At least one of the energy absorbers may include a metal oxide. In particular, each energy absorber may include a metal oxide. The metal oxide may be for example ZnO. In embodiments, at least one of the energy absorbers may be a metal oxide varistor. In further embodiments, each energy absorber may be a metal oxide varistor.

[0091] In embodiments, at least one of the one or more energy absorbers may include multiple energy absorption blocks. The energy absorber may further include heat sinks positioned between the energy absorption blocks. The heat sinks may include aluminum or copper.

[0092] In embodiments, the energy absorption device may include an energy absorber with one or more cavities. The cavities may be embodied as channels. The fluid distribution unit may be configured to guide a cooling fluid at least partially into the cavities. In embodiments, there may be heat transport elements arranged in the cavities. The heat transport elements may be configured to transport heat from an inner region of the energy absorber to the surface of the energy absorber. Thus, the cooling rate may be improved. The thermal recovery time may be reduced. The heat transport elements may include a material with a high thermal conductivity, for example copper or aluminum. In embodiments, the energy absorber has a central channel that connects an upper region of the energy absorber with a lower region of the energy absorber. Typically, the energy absorber is column-shaped. The energy absorber may in particular be cylinder-shaped.

[0093] An energy absorption device comprising one or more metal oxide varistors may generate a counter voltage when a switching event occurs in the circuit breaker, the circuit breaker being a direct current circuit breaker. The counter voltage may force the current to zero. Therefore, HCBs and SSCBs with energy absorption devices

comprising one or more metal oxide varistors are especially attractive for switching direct current.

[0094] The two-phase cooling arrangement can be an arrangement configured to provide a cooling fluid in a liquid state to a unit to be cooled, wherein the cooling fluid may at least partially evaporate in proximity to or on contact with the unit to be cooled.

[0095] Utilizing a two-phase cooling arrangement can greatly increase the heat transfer as compared to cooling by natural convection. A remarkable reduction of the cooling time can be achieved.

[0096] The two-phase cooling arrangement may be configured to cool at least one of the one or more energy absorbers. Utilizing a two-phase cooling arrangement can make it possible to reduce the size of at least one of the one or more energy absorbers. Thereby costs may be saved. It can also lead to a reduction of space required by the one or more energy absorbers. A reduction of the space required by the energy absorption device may be achieved.

[0097] Utilizing a two-phase cooling arrangement can also make it possible to reduce the number of energy absorbers. Thereby costs may be saved. This can lead to a reduction of space required by the one or more energy absorbers. A reduction of the space required by the energy absorption device may be achieved. Energy absorption devices that take up less space can be particularly desired, for example if they are intended to be used on an off-shore platform.

[0098] A cooling fluid of the two-phase cooling arrangement may be one of Novec 649, C5, C6, Novec HFE7100 or Novec HFE7500. Novec HFE7500 is particularly well suited, since it has a high boiling point and can be well combined with dielectric gases like SF₆ and N₂. Generally, a cooling fluid may be utilized that is dielectric and that has a low global warming potential. Particularly a non-toxic and nonflammable cooling fluid may be utilized. Thus, dangers associated with a release of the cooling fluid, for example in case of an emergency, may be limited.

[0099] Generally, embodiments of the energy absorption device can be configured to be suitable for all conceivable voltage levels.

[0100] The energy absorption device may include two or more energy absorbers connected electrically in series. In particular, by connecting a plurality of energy absorbers electrically in series, an energy absorption device for a higher system voltage may be provided. In embodiments, at least two of the two or more energy absorbers connected electrically in series may be positioned within a shared enclosure.

[0101] The energy absorption device may include two or more energy absorbers connected electrically in parallel. This may improve the energy handling capability and/or the energy rating of the energy absorption device. At least two of the two or more energy absorbers connected electrically in parallel may be positioned within a shared enclosure. For example, the energy absorption

device may include two or three energy absorbers connected electrically in parallel, the two or three energy absorbers being arranged within one enclosure.

[0102] In embodiments, the energy absorption device may include two or more enclosures. In each of the two or more enclosures a set of two or more energy absorbers, such as three, four or even more energy absorbers, may be positioned. A first set of energy absorbers arranged within a first shared enclosure may be connected electrically in series or in parallel to a second set of energy absorbers arranged within a second shared enclosure.

[0103] The one or more fluid distribution units of the two-phase cooling arrangement may be configured to direct a cooling fluid in a liquid state toward all energy absorbers arranged within a shared enclosure.

[0104] The energy absorption device may include one or more condensers. Each enclosure may be connected to one or more condensers. In embodiments, each enclosure may be connected to a separate condenser. The condensers may be connected to a common cooling circuit. Instead, each condenser may be connected to a separate cooling circuit.

[0105] The cooling circuit may have a first pump and a second pump for redundancy.

[0106] At least one of the one or more enclosures may hold a dielectric gas, in particular SF₆, N₂, CO₂ or air. One or more components of the dielectric gas may be non-condensable and/or immiscible. The two-phase cooling arrangement may be configured to generate a mixture, in particular a two-phase mixture of the cooling fluid with the dielectric gas by distributing the cooling fluid in the enclosure.

[0107] The two-phase cooling arrangement may include one or more fluid distribution units. The one or more fluid distribution units may be arranged within the enclosure. The one or more fluid distribution units may be configured to distribute the cooling fluid as a jet, spray, mist or film. The film may be embodied as a falling film.

[0108] In embodiments, the fluid distribution unit may include one or more nozzles, at least one of the one or more nozzles being embodied as an upper nozzle. The upper nozzle may be positioned approximately at a same height as an upper region of the energy absorber. The upper nozzle may be configured to direct the cooling fluid toward the upper region of the energy absorber.

[0109] Furthermore, at least one of the one or more nozzles may be embodied as a middle nozzle. The middle nozzle may be positioned approximately at a height of a middle region of the energy absorber. The middle nozzle may be configured to direct the cooling fluid toward the middle region of the energy absorber.

[0110] In the context of the present disclosure, a middle region of the energy absorber is in particular to be understood as being a region located at a height approximately halfway between a height of an upper region of the energy absorber and a height of a lower region of the energy absorber. "Halfway" in this context can be understood as a region of between 40% and 60% of the energy

absorber's length as measured from the energy absorber's bottom.

[0111] In embodiments, the energy absorption device may further include a liquid guiding unit configured to guide the cooling fluid flowing from the liquid storage volume so as to come into contact with the energy absorber in an upper region of the energy absorber. The liquid guiding unit may be configured to guide the cooling fluid flowing from the liquid storage volume so as to come into contact with the energy absorber in an upper region of the energy absorber and additionally in a middle region of the energy absorber. The liquid guiding unit may include one or more pipes. The liquid guiding unit may include one or more plates. The liquid guiding unit is particularly made from an isolating material.

[0112] The energy absorption device may further include one or more pressure relief valves, in particular as a protection against explosions, particularly explosions due to rapid heating of cooling fluid that has accumulated within the enclosure in a liquid state. In particular, at least one of the one or more enclosures may include one or more pressure relief valves. In embodiments, each enclosure may include one or more pressure relief valves.

Claims

1. Energy absorption device (1) for a circuit breaker, in particular a solid-state or a hybrid circuit breaker, the energy absorption device (1) comprising an energy absorber (20) arranged within an enclosure (10) and a two-phase cooling arrangement with one or more fluid distribution units (110) configured to direct a cooling fluid in a liquid state toward the energy absorber (20), the energy absorber (20) being cooled due to evaporation of the cooling fluid.
2. Energy absorption device (1) according to claim 1, wherein the energy absorber (20) is a varistor and/or the two-phase cooling arrangement further comprises a liquid return unit (136, 145) configured to return the cooling fluid from the enclosure (10) to a liquid storage volume (125).
3. Energy absorption device (1) according to claim 1 or 2, the two-phase cooling arrangement further comprising one or more condensers (120, 121) connected to the enclosure (10), the one or more condensers (120, 121) being configured to facilitate condensation of the cooling fluid that has evaporated within the enclosure (10).
4. Energy absorption device (1) according to any of the preceding claims, the one or more fluid distribution units (110) being arranged at a distance of at least 1 cm and/or at most 50 cm from the energy absorber (20).
5. Energy absorption device (1) according to any of the preceding claims, the one or more fluid distribution units (110) comprising one or more nozzles (111), the two-phase cooling arrangement further comprising a fluid transportation unit (130, 140) configured to transport a cooling fluid from a liquid storage volume (125) to the one or more fluid distribution units (110).
6. Energy absorption device (1) according to any of claims 1 to 4, the one or more fluid distribution units (110) being embodied as a liquid release unit (110) configured to be switchable between a holding state and a releasing state, and to release the cooling fluid that is stored in the liquid storage volume (125) when the liquid release unit (110) is in the releasing state, wherein the release of the cooling fluid allows the cooling fluid to flow onto the energy absorber (20) due to gravitation.
7. Energy absorption device (1) according to any of claims 1 to 5, at least one of the one or more nozzles (111) being embodied as an upper nozzle (111), the upper nozzle (111) being positioned in an upper region of the enclosure (10) and being configured to direct the cooling fluid toward an upper region of the energy absorber (20).
8. Energy absorption device (1) according to claim 2 and optionally any of claims 3 to 7, further comprising a control unit (150) configured to receive signals from one or both of a temperature sensor (50) and a cooling liquid level sensor (52) and to activate the liquid return unit (136, 145) in dependence on the signals.
9. Energy absorption device (1) according to any of the claims 1 to 7, the energy absorption device (1) further comprising a control unit (150) configured to activate the fluid transportation unit (130, 140) or to switch the liquid release unit (110) to the releasing state when a switching event occurs in the circuit breaker.
10. Energy absorption device (1) according to claim 8 or 9, the control unit (150) further being configured to receive signals from one or both of a temperature sensor (50) and a cooling liquid level sensor (52) and, depending on the signals received, to control the fluid transportation unit (130, 140) or the liquid release unit (110) so as to change the flow rate.
11. Energy absorption device (1) according to claim 6, the two-phase cooling arrangement further comprising a liquid guiding unit configured to guide the cooling fluid flowing from the liquid storage volume (125) so as to come into contact with the energy absorber (20) in an upper region of the energy absorber (20) and optionally in a middle region of the energy absorber (20).

12. Circuit breaker, in particular solid-state or hybrid direct current circuit breaker, comprising one or more energy absorption devices (2, 3, 4) according to any of the preceding claims. 5
13. Method for two-phase cooling of an energy absorber (20) of a circuit breaker, in particular a solid-state or hybrid direct current circuit breaker, the method comprising: 10
- after a switching operation of the circuit breaker, directing a cooling fluid in a liquid state toward the energy absorber (20), thereby cooling the energy absorber (20) due to evaporation of the cooling fluid. 15
14. Method according to claim 13, the method further comprising: 20
- regulating the flow rate of the cooling fluid toward the energy absorber (20) depending on signals from one or both of a measured temperature and a measured cooling liquid level.
15. Method according to claim 14, wherein the energy absorber (20) is arranged within the enclosure (20), the method further comprising: 25
- returning cooling fluid from an enclosure (10) to a liquid storage volume (125). 30

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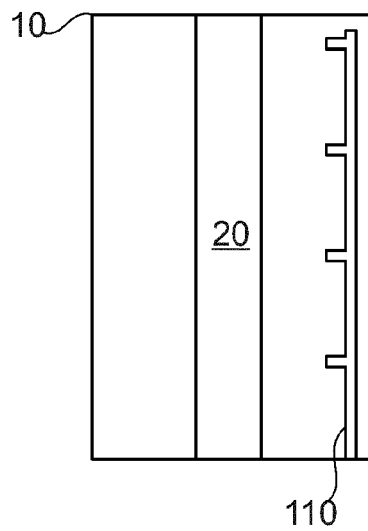


Fig. 1

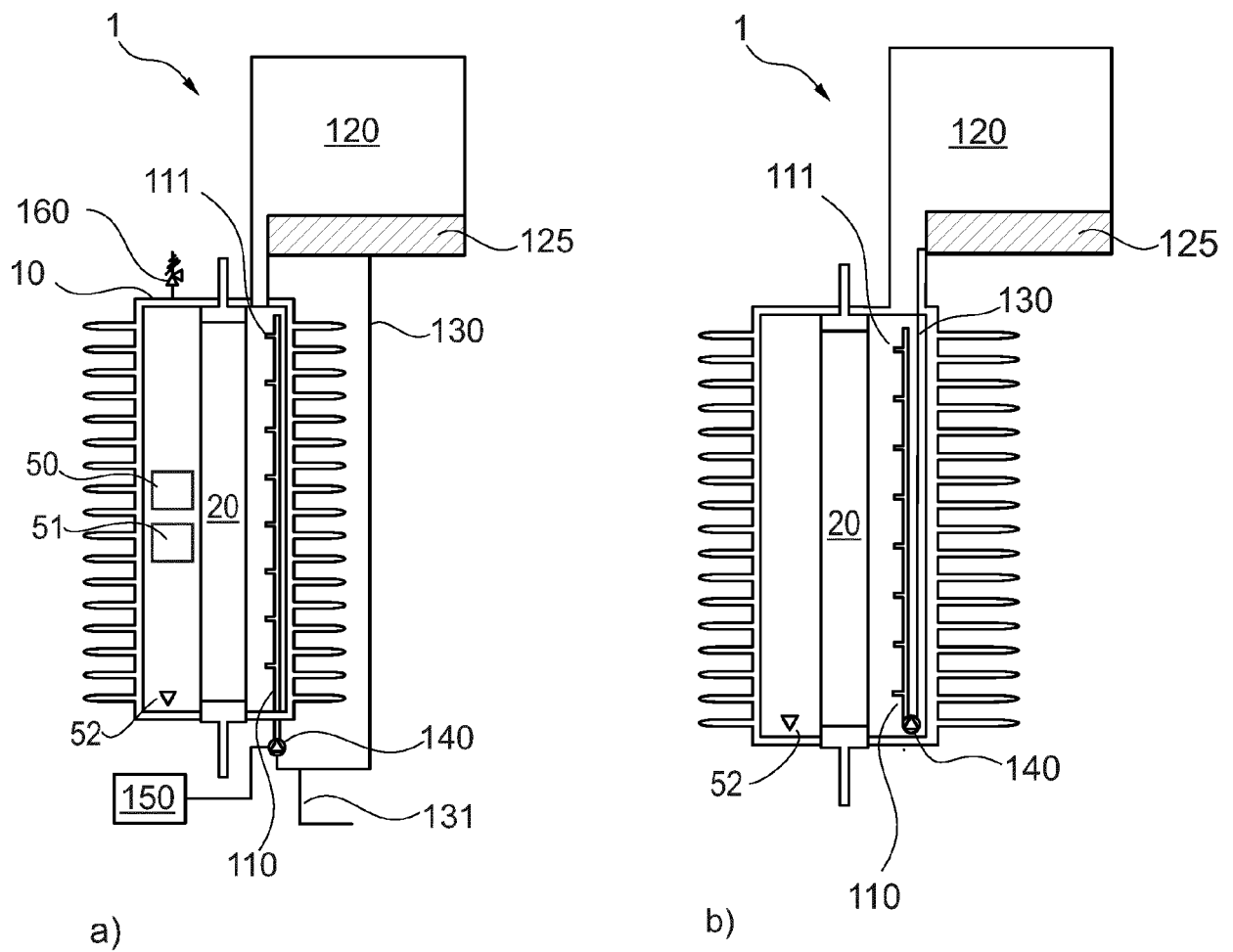


Fig. 2

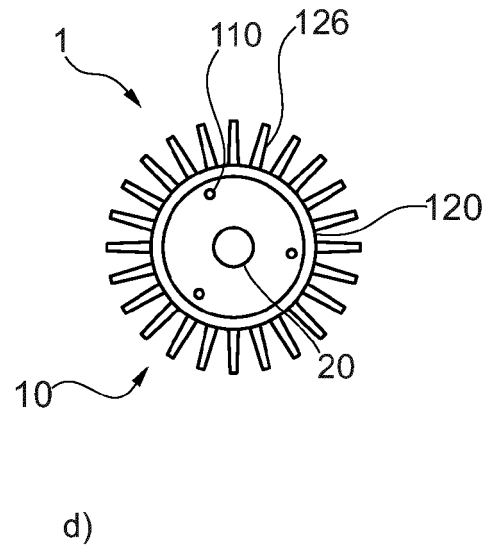
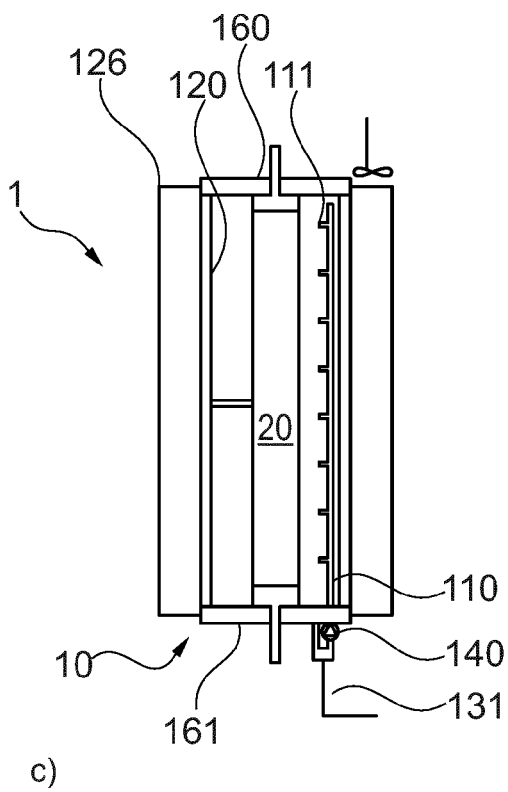
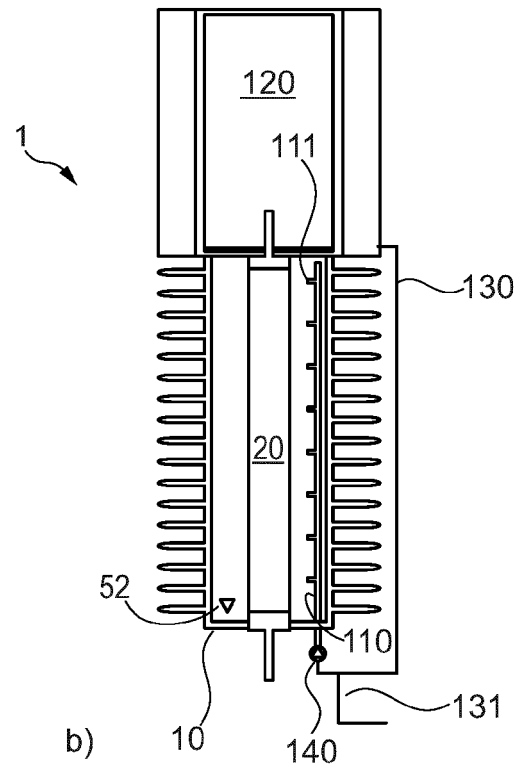
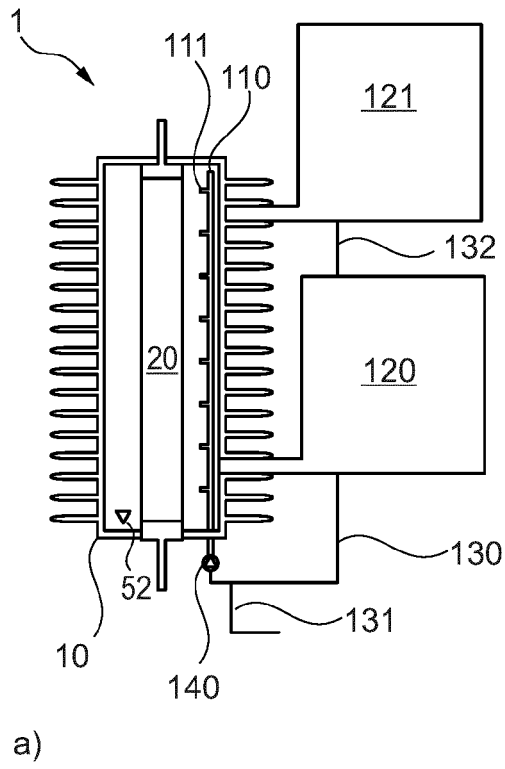


Fig. 3

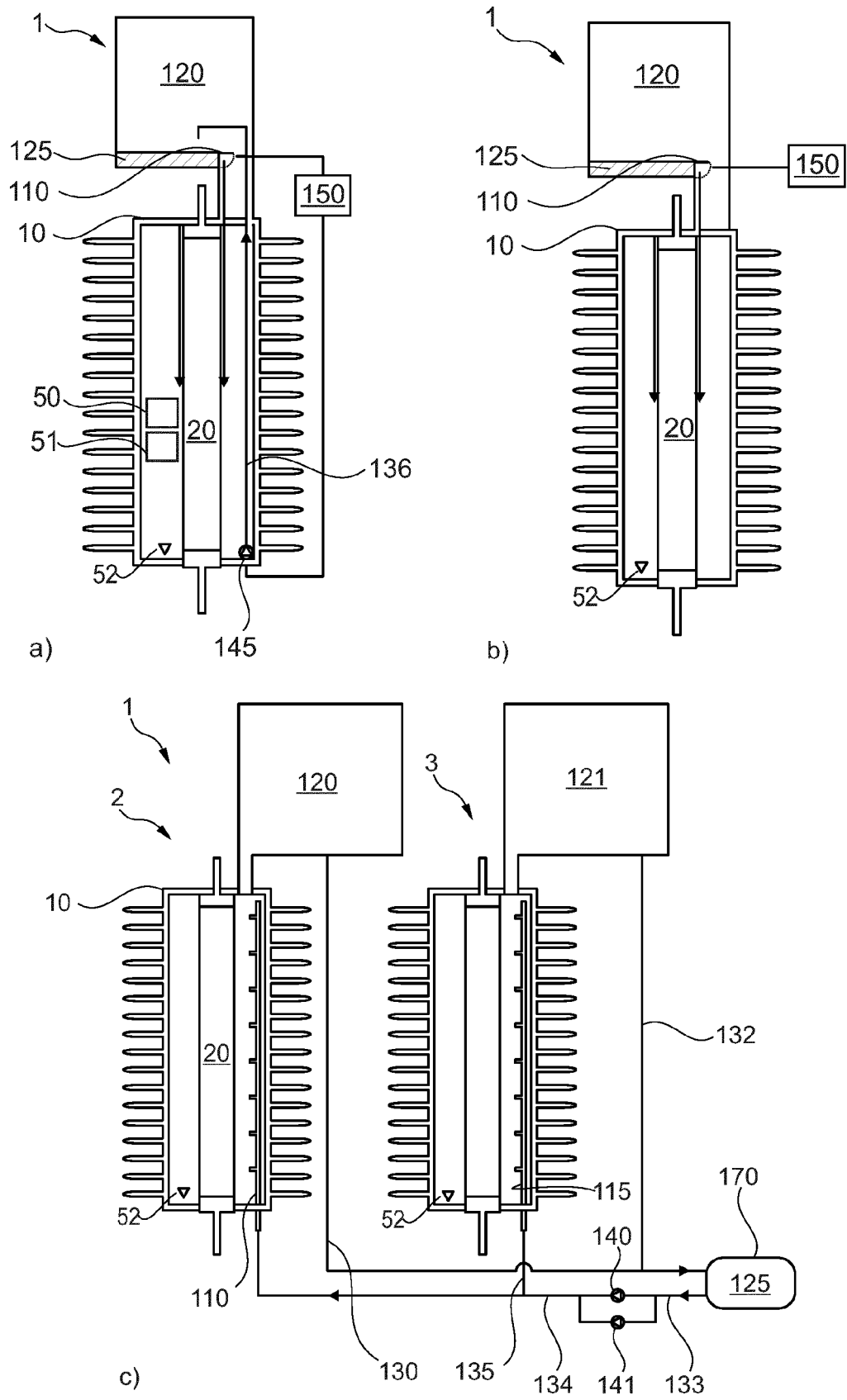


Fig. 4

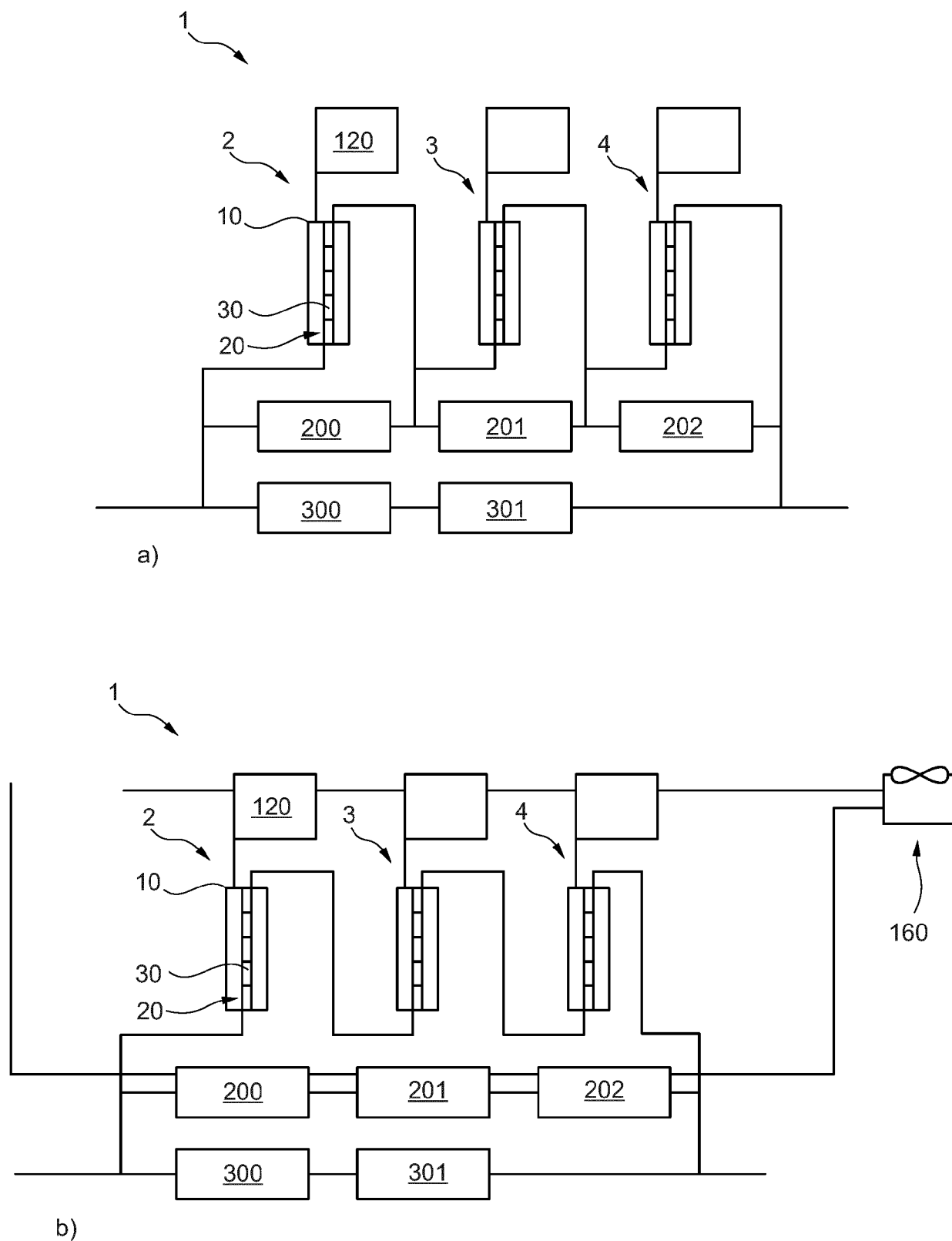


Fig. 5



EUROPEAN SEARCH REPORT

Application Number
EP 18 17 3212

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The present search report has been drawn up for all claims			
Place of search Munich		Date of completion of the search 21 November 2018	Examiner Frias Rebelo, Artur
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	

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**ANNEX TO THE EUROPEAN SEARCH REPORT
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5 This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
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