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(71) Applicant: **GE Energy Power Conversion Technology Ltd**
Rugby
Warwickshire CV21 1BU (GB)

(72) Inventor: **Crane, Allan David**
RUGBY, Warwickshire CV21 1BU (GB)

(74) Representative: **Serjeants LLP**
Dock
75 Exploration Drive
Leicester, LE4 5NU (GB)

(54) Circuit Breakers

(57) A circuit breaker is described. The circuit breaker includes one or more arcing contact modules (202). Each arcing contact module typically includes a first dielectric fluid inlet (222), a first stationary contact (208), at least one second stationary contact (210), and at least one moving contact (220). The first and second stationary contacts (208, 210) are spaced apart by a gap that defines a dielectric fluid outlet (212). Each moving contact (220) is movable using hydraulic actuation. Pressurised dielectric fluid is introduced through the first inlet (222) to move each moving contact (220) from a first position to a second position. Arcing can be initiated by the movement of the moving contact (220) and the introduced pressurised dielectric fluid is blasted through the outlet (212) to cool and extinguish the arc.

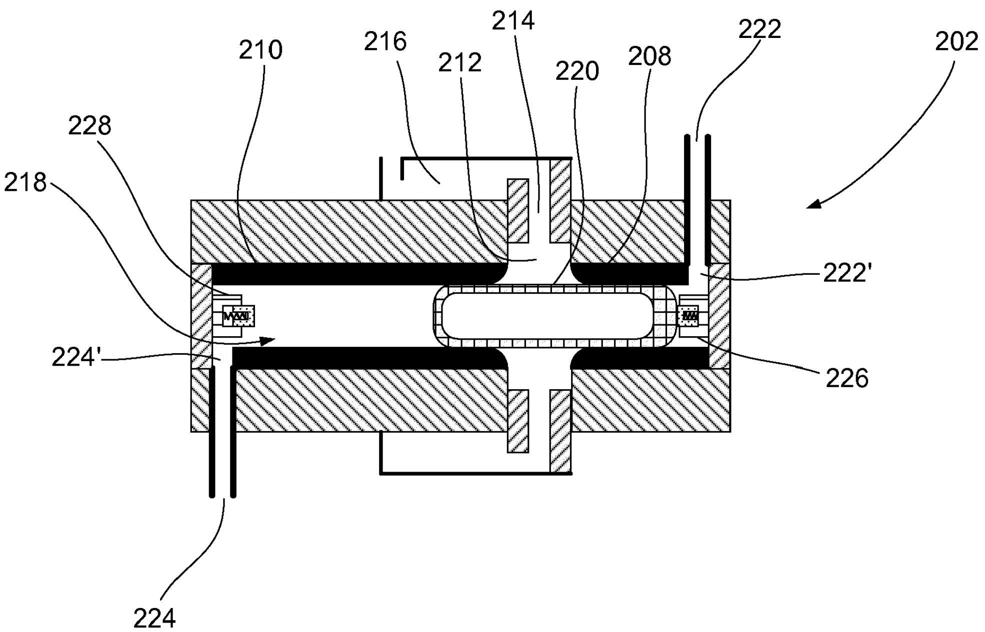

Figure 7

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Description

Field of the Invention

[0001] The present invention relates to circuit breakers, and in particular to circuit breakers for use in direct current (dc) circuits or alternating current (ac) circuits.

Background Art

[0002] Examples of high voltage alternating current (HVAC) circuit breakers that employ rapidly flowing dielectric fluids to de-ionise an arc include: oil explosion pot, minimum oil, air blast and SF6 puffer types with series connected contacts and nonlinear or linear resistive and capacitive voltage sharing. Although it is intended that the series-connected contacts of such circuit breakers generally operate in mechanical synchronism, as circuit breakers employ more contacts in series and as voltage ratings increase, the effect of the response of the actuating linkages and control systems is to cause contacts to be actuated at differing rates and at different times. All of the circuit breakers have a limited capability to develop arc voltage, relying instead on the inherent current zeros that occur in ac currents to initiate arc extinction. The described mechanical synchronisation limitations are not of great significance in present HVAC circuit breakers because electrical synchronisation dominates, i.e., all contacts experience the same current zero condition since they are connected in series. In these circuit breakers, contact actuation is by means of a mechanical linkage which may be driven by a range of electromagnetic, pneumatic, hydraulic and spring devices, such devices commonly being provided with energy storage means. These known circuit breakers have insignificant capability to interrupt current in HVDC circuits.

[0003] Series-connected and parallel-connected arrays of known HVAC circuit breakers have been proposed as a means of reducing the switching stress in any particular element within the array to tolerable levels when switching HVDC circuits, but all such proposals have been shown to be non-viable.

[0004] Known HVAC circuit breakers have been adapted for use in HVDC circuits by hybridisation with other technologies that forcibly cause current zeros and arc extinction to occur in the circuit breaker. These hybridisation arrangements fall within the following basic descriptions:

(i) Where a series resonant circuit is connected in parallel with the circuit breaker contacts, arc instability is promoted by the low impedance of the parallel-connected resonant circuit, and where the amplitude of the associated resonant current increases until current zeros occur in the circuit breaker.

(ii) Where a pre-charged capacitor is connected in parallel with the circuit breaker contacts by turning on a power electronic switching device, and where the polarity of the pre-charge is such as to cause a current zero to occur in the circuit breaker.

(iii) Where a power electronic switching device assembly is connected in series with the circuit breaker and the power electronic switching device assembly is actively turned off, thereby causing a current zero to occur in the circuit breaker.

[0005] Since HVDC circuits contain significant series inductance, any attempt to interrupt current results in the generation of a transient voltage and a requirement to dissipate the inductively stored energy. It is therefore a mandatory requirement that the above hybridised arrangements are used in conjunction with a surge arrester. It is commonplace for hybridised HVDC circuit breakers to be used in conjunction with a metal oxide varistor (MOV) type surge arrester that is connected in parallel with the hybrid circuit breaker and/or between one terminal of the hybrid circuit breaker and ground. Moreover, hybrid arrangement (iii) requires that current is rapidly diverted into a switching aid network or additional power electronic circuit breaker that is connected in parallel with the series-connected power electronic switching device assembly and circuit breaker.

[0006] A further limitation of known HVAC circuit breakers is their low operating speed. It is commonplace for circuit breaker contacts to start to separate after a delay of at least 10 ms and often more than 20 ms (excluding delays in protection relays and controlling devices). Moreover, once circuit breaker contacts have started to separate it may take a further 10 ms or much more for full contact separation to be established. As more contacts are series connected in order to achieve a high working voltage capability, the physical size of the circuit breaker becomes a significant factor in limiting the operating speed because longer and more compliant contact actuation linkages are required.

[0007] Emerging HVDC circuit breaker requirements are extremely stringent because prospective fault energy, fault current and rate of increase of fault current are sufficiently high to require a circuit breaker total opening time, prior to diversion of current into the surge arrester, in the region of 2 ms. Although it is possible to add series inductance to limit the rate of increase of fault current, this simply increases the total fault energy per unit interrupted current. Whilst it is the case that the power electronic switching devices of hybrid arrangements (ii) and (iii) may be turned on and off, respectively, in less than 5 μs, there remains a requirement for an extremely fast acting (circa 2 ms) mechanical switching device to be employed if the ratings, size and complexity of hybridisation components, e.g., IGBTs and capacitors, are to be brought within commercially viable limits.

[0008] Further requirements are that continuous 'on' state power loss must be minimised in the interest of reduced 'loss capitalisation' and that HVDC circuit breakers must be extremely dependable in the interest of power network availability. Accordingly there is a desire to eliminate any requirement to have power semiconductor or other active devices in the continuous 'on' state path. The current in a modern HVDC network may flow in either direction in accordance with the direction of power flow and it is desirable that this bidirectional capability be provided without requiring additional power components.

[0009] A circuit breaker that requires no additional components beyond a surge arrester would be very desirable from the perspective of simplicity and in having low continuous 'on' state power losses.

Summary of the Invention

[0010] An objective of the present invention is to produce a circuit breaker whose arc voltage starts to increase after the minimum possible delay, and preferably less than 2 ms from receipt of a signal to open. Thereafter, arc voltage will increase rapidly and preferably attain its maximum prospective level within 4 ms from receipt of a signal to open. The circuit breaker includes a moving contact that is actuated by a pressurised dielectric fluid to initiate arcing and where the pressurised dielectric fluid is also used to extinguish the arc.

[0011] A further objective of the present invention is that the circuit breaker is modular and scalable.

[0012] The present invention provides a circuit breaker comprising at least one arcing contact module, each arcing contact module comprising:

a first dielectric fluid inlet;
a first stationary contact;
a second stationary contact, the first and second stationary contacts being spaced apart by a gap that defines a dielectric fluid outlet; and
a moving contact, the moving contact being movable (without any mechanical linkage) by the introduction of pressurised dielectric fluid through the first inlet from:

(a) a first position, to
(b) a second position,
to activate the circuit breaker.

[0013] The circuit breaker can be used with either dc circuits (e.g., LVDC, MVDC or HVDC circuits) or ac circuits (e.g., LVAC, MVAC or HVAC circuits) as required. For ac circuits, the circuit breaker can include at least one arcing module for each phase of the ac circuit. For example, if the ac circuit is a three-phase circuit, the circuit breaker can have three arcing contact modules. Each arcing contact module can have any suitable number of moving contacts and associated stationary contacts, inlets, outlets, fluid actuation means etc.

[0014] In one arrangement, in the first position the moving contact is in electrical contact with the first and second stationary contacts to provide an electrically conductive pathway between the first and second stationary contacts, and in the second position the moving contact is not in electrical contact with the first stationary contact. Movement of the moving contact from the first position towards the second position establishes an arc across the gap between the first and second stationary contacts, i.e., arcing is initiated as the moving contact moves from the first (or open) position towards the second (or closed) position. The introduced pressurised dielectric fluid flows through the outlet to cool the arc. In this arrangement, each arcing module is opened for protection purposes, e.g., so a faulty load is no longer is electrical contact with a power supply. The arrangement will therefore be referred to herein as an 'open to protect' arrangement.

[0015] In another arrangement, in the first position the moving contact is not in electrical contact with the first stationary contact, and in the second position the moving contact is in electrical contact with the first and second stationary contacts to provide an electrically conductive pathway between the first and second stationary contacts. Movement of the moving contact from the first (or open) position towards the second (or closed) position will not normally be associated with any arcing but a voltage breakdown between the rapidly converging moving contact and first stationary contact is likely just before they come into contact. Although arcing is not expected under normal circumstances, the circuit breaker would typically have an ability to withstand arcing and would capable of interrupting current. In this arrangement, each arcing module is closed for protection purposes, e.g., so fault current is diverted to a ground connection. Fault current may optionally be diverted between lines. This arrangement will therefore be referred to herein as a 'close to protect' arrangement.

[0016] A single moving contact or a pair of moving contacts can optionally be provided within an arcing contact module. The circuit breaker can provide multiple breaks in each dc or ac circuit line. For example, arcing contact modules can be configured as a single-, double- or multi-break contact system. In an open to protect arrangement, the first inlet can be positioned to cause the moving contacts to move in opposite directions as a result of the introduction of the pressurised dielectric fluid. In other words, a pair of moving contacts can have a common first inlet located between them so that the moving contacts move apart from each other. In a close to protect arrangement, a pair of first inlets can be positioned to cause the moving contacts to move in opposite directions as a result of the introduction of the pressurised dielectric fluid. In other words, a pair of moving contacts can be located between a pair of first inlets so that the moving contacts move towards each other.

[0017] The circuit breaker is constructed from one or more arcing contact modules and it is preferable that all arcing contact modules within a circuit breaker are of the same type, i.e., it is not preferred that single-break and double-break modules are mixed within a particular circuit breaker because they may not have substantially identical performance. In an open to protect arrangement, each arcing contact module can include a first inlet, a pair of moving contacts (a moving contact being disposed on each side of the first inlet so that they are forced to move in opposite directions by the introduced pressurised dielectric fluid), a first stationary contact, a pair of second stationary contacts, and a pair of outlets. In a close to protect arrangement, each arcing contact module can include a pair of first inlets, a pair of moving contacts (the moving contacts being disposed between the first inlets so that they are forced to move in opposite directions by the introduced pressurised dielectric fluid), a first stationary contact, a pair of second stationary contacts, and a pair of outlets. In general terms, circuit breakers having an open to protect arrangement or a close to protect arrangement will have very similar construction and might be manufactured using identical components. As noted herein, a circuit breaker having a close to protect arrangement would not normally be required to interrupt significant (if any) fault current and the overall construction can therefore be simplified in some situations by altering the components of the circuit breaker that: (a) permit the rapid removal of the initially hot gas/liquid mixture that is normally a result of arcing, (b) allow the arcing region to be flushed with dielectric fluid immediately after arc extinction, (c) allow the continuous, slow, purge of the arcing region of any gas bubbles that might constitute a risk of flashover, and (d) are specified to withstand arcing, e.g., the outlets/vents, the stationary and moving contacts etc. A circuit breaker having a close to protect arrangement might also use an activating fluid actuation system (see below) that operates with a lower pressure and/or smaller volume.

[0018] The circuit breaker might include a plurality of such arcing contact modules arranged in series or parallel, each being activated in a synchronous manner on receipt of a signal to activate the circuit breaker for protection purposes. The number and arrangement of arcing contact modules will be selected with reference to a desired arc voltage or total arcing performance. The designer is free to employ a relatively large number of moving contacts, each having a relatively small stroke, in the interest of achieving maximum practical operating speed, i.e., defining that the actuation energy per moving contact is minimised with due regard for the compromise between speed and complexity, and also taking into account that arc voltage and transient recovery voltage withstand are less than proportional to contact separation. All arcing contact modules can be controlled by a suitable control unit that receives a signal to activate the circuit breaker for protection purposes when a fault current is developed, or in response to an externally generated trip request, or in response to an operator request.

[0019] The first and second stationary contacts can be substantially tubular defining a linear passageway in fluid communication with each first inlet and outlet. Each moving contact can be positioned within the linear passageway. Each moving contact can have a substantially cylindrical shape and preferably has a relatively low mass. In particular, the mass of each moving contact can be minimised by providing an internal cavity.

[0020] The interface between corresponding moving and stationary contacts can be defined as having three regions, namely a fluid sealing region, an electrical sliding contact region, and an arc erosion resistant region.

[0021] Each moving contact is preferably a close fit within the linear passageway. One or both of each moving contact and the surrounding stationary contacts can be constructed (e.g., shaped) to minimise leakage of dielectric fluid past the moving contact, but some leakage may be tolerated in practice. Generally it is preferred that moving and stationary contacts have dimensional tolerances that minimise leakage without recourse to the use of additional sealing means, but such sealing means (e.g., O-rings and gland seals) can optionally be employed where appropriate. In one arrangement, where the dielectric fluid is a liquid, the viscosity of the liquid can also restrict leakage to an acceptable level.

[0022] One or both of each moving contact and the surrounding stationary contacts can be constructed (e.g., shaped or formed of a suitable material) to minimise electrical contact resistance therebetween. Generally it is preferred that the bulk of the moving and stationary contacts are made of a metal or metal alloy with a high electrical conductivity and that the stationary contacts in particular have a region that benefits from a radially inwardly directed bias force in order to ensure reliable electrical sliding contact with the moving contact. The bias force may be facilitated by segmenting at least a part of each stationary contact (e.g., in an electrical sliding contact region) so that it provides a spring pre-load. The segmented stationary contact would be deflected radially outwardly against the spring pre-load by the moving contact so that a desired electrical sliding contact force is provided therebetween. Other ways of providing a bias force will be known to the skilled person. Typically, the electrical sliding contact resistance will be sufficiently low to ensure that there is substantially no passage of current through the fluid sealing region.

[0023] One or both of each moving contact and the surrounding stationary contacts can be constructed (e.g., shaped or formed of a suitable material) to minimise erosion as a result of arcing. It will be readily appreciated that, for an open to protect arrangement, when the moving contact is initially separated from the first stationary contact upon movement towards a fully open position, one or more arcs will be established between the moving contact and the first stationary contact. Generally it is preferred that the arc-facing regions of the stationary and moving contacts are resistant to the intense heat of the arc and that their arc-facing geometries do not tend to concentrate both current density and heat flux density whilst locally increasing thermal resistance. Copper chromium, copper tungsten and molybdenum alloys that are commonly used in other switch contact technologies might be deposited or otherwise used in the arc-facing regions. The arc-facing regions may be of sufficient thickness and have sufficient mass to provide a transient thermal resistance that is sufficiently low to minimise the degree of contact erosion. Arc-facing extremities of the moving and stationary contacts can be machined to give a radiused profile.

[0024] In one arrangement, each moving contact can be a lightweight aluminium alloy cylindrical body upon which a high electrical conductivity and wear-resistant layer is applied or deposited in order to facilitate the sliding contact mechanism, and have a suitably profiled arc erosion-resistant arcing face or contact tip.

[0025] The present invention relies on fluid actuation of each moving contact by the pressurised dielectric fluid that is introduced through each first inlet, and in the case of the open to protect arrangement, using actuating fluid flow to blast the dielectric fluid through each outlet, thereby rapidly removing heat and ionised material from each arc in order to cause its extinction. In other words, the pressurised dielectric fluid fulfils two important technical functions, namely fluid actuation of the moving contact(s) and arc cooling. In the case of ac circuits, the circuit breaker will normally cause arc extinction without relying upon a naturally occurring or forced current reversal.

[0026] A suitable number of moving contacts are actuated simultaneously, with minimal delay and, in the case of the open to protect arrangement, with rapidly increasing contact separation. As such, the initiation of arcing is expected to be subject to the minimum practical delay and the total arc voltage is expected to increase rapidly to an unusually large magnitude. The desired total arc voltage and rate of change of arc voltage, and the equalisation of arc voltages, is substantially achieved by using a suitable number of series-connected arcing contact modules whose actuation means comprises a suitable number of parallel-connected or independent fluid paths. Although the equalisation of arc voltage is substantially achieved as described, additional voltage equalisation means may be electrically parallel connected with each switch contact system within each arcing contact module - an arcing contact module with a single moving contact defines a single switch contact (or single-break) system whereas an arcing contact module with two moving contacts defines a two switch contact (or double-break) system wherein both switches (or breaks) are inherently series connected. Two such double-break systems may be connected in series in order to define a quadruple-break system, and so on.

[0027] The circuit breaker preferably further includes an activating fluid actuation system that it is fluidly connected to each first inlet. In an arrangement where the circuit breaker includes a plurality of first inlets (e.g., a plurality of series-connected arcing contact modules), each first inlet can be connected to its own fast-acting fluid actuation means that includes an activating accumulator for storing the pressurised dielectric fluid, a release valve and associated passageways. But fluid actuation means can also be shared by two or more first inlets. For example, the activating fluid actuation system can include a single activating accumulator that is connected to each first inlet, either by a single release valve or by a series of release valves (i.e., each first inlet has its own respective release valve). Each release valve is opened and closed under the control of a control unit. Each release valve can have any suitable construction but will preferably be extremely fast-acting, e.g., with opening times typically less than about 0.5 ms. In one arrangement, poppet-type release valves with electromagnetic repulsion-type actuation can be employed. On receipt of a signal to activate the circuit breaker for protection purposes, each release valve is opened to allow the pressurised dielectric fluid in the associated activating accumulator to flow through each first inlet to provide the fluid actuation that forces the moving contact(s) towards the open or closed position. Where the activating fluid actuation system includes two or more release valves they are preferably controlled to open substantially simultaneously to ensure proper synchronisation of the arcing contact modules. In the case of the open to protect arrangement, the action of the arc that forms as each moving contact separates from the surrounding first stationary contact causes thermal decomposition of the dielectric fluid, and in the case of the preferred dielectric liquids, the resultant generation of gaseous products causes additional actuating pressure to be applied to the moving contact(s). This allows some economy to be made in sizing the activating accumulator(s) but there must be sufficient capacity to accommodate the case where only a small current is interrupted by the circuit breaker and arc energy is insufficient to cause the development of gas pressure that would otherwise supplement the fluid actuation of the moving contact.

[0028] It will be readily appreciated that the term 'accumulator' is intended to refer to any suitable pressure storage reservoir or device for the dielectric fluid. The ability of such an accumulator to rapidly release its stored energy when discharged into the fluid actuation system is an essential aspect of the present invention and therefore the preferred form of accumulator is one where the energy is stored in a compressible gas and where this energy acts upon an actuating fluid that is in the liquid phase. As such, the actuating fluid will be substantially incompressible and will exhibit a beneficially high speed of sound. However, it is within the scope of the present invention that the energy storage medium and the actuating fluid may be of the same medium, also that the energy is stored in other ways, e.g., by a mechanical spring device.

[0029] In one arrangement, the opening of a release valve will cause a pressure wave to propagate from the release valve to the moving contact(s) at substantially the speed of sound, which is typically greater than about 1.3 km/s in the preferred dielectric liquids. The tensile compliance of the fluid connection between activating accumulator and the release valve will typically have little impact upon the speed of the pressure wave but that of the fluid connection between the release valve and the moving contact(s) causes a small reduction in the speed of the pressure wave. In practice it is expected that activating accumulator pressure can be applied to the moving contact(s) within about 200 μs of a release valve being opened. In this context, the term, 'opened' is used to define the point in time when the valve peripheral sealing face first separates from the corresponding valve seat; thereafter the valve open area increases rapidly whilst the flow of actuating fluid increases correspondingly. The present invention therefore overcomes the mechanical operating speed limitations of known multiple contact actuation linkages. Contact actuation speed is not compromised as the number of moving contacts is increased. Moving contacts are all actuated with substantially identical performance, including those in parallel-connected or series-connected arcing contact modules which can be constructed as completely separate units that are operated together to define the circuit breaker.

[0030] It is often necessary to be able to move each moving contact back towards the first position when the circuit breaker needs to be reset. Although any suitable means (including mechanical means) can be provided for moving contact resetting, fluid actuation is preferably used for both activating and resetting of the circuit breaker and the circuit breaker also preferably includes a resetting fluid actuation system. Each arcing contact module preferably further includes a second dielectric fluid inlet. For an open to protect arrangement, if each arcing contact module includes a pair of moving contacts then a pair of second inlets are typically also provided with the first inlet and the outlets being positioned between them. For a close to protect arrangement, if each arcing module includes a pair of moving contacts then a common second inlet is typically provided between them so that the moving contacts move apart from each other during circuit breaker resetting.

[0031] Each moving contact has a first end which faces towards an associated first inlet and a second end which faces towards an associated second inlet. In the case of an open to protect arrangement, a pair of moving contacts (e.g., from physically adjacent arcing contact modules) can also share a common second inlet.

[0032] The resetting fluid actuation system may have a similar overall construction to the activating fluid actuation system but a lower-performance resetting accumulator and release valve arrangement may be specified. The activating and resetting fluid actuation systems are typically separate, but may be integrated with suitable means (e.g., control valves) being provided to direct the pressurised dielectric fluid to each first inlet or second inlet as required for circuit breaker activation and resetting, respectively. In general terms, it will be readily appreciated that the circuit breaker is activated for protection purposes by introducing pressurised dielectric fluid from the activating fluid actuation system through each first inlet to force each moving contact towards the second position and, in the case of an open to protect arrangement, to initiate arcing between the first and second stationary contacts. The circuit breaker is reset by introducing pressurised dielectric fluid from the resetting fluid actuation system through each second inlet to force each moving contact back towards the first position where, in the case of an open to protect arrangement, the electrically conductive pathway between the first and second stationary contacts is re-established. In the case of a close to protect arrangement, the circuit breaker is activated for protection purposes by introducing pressurised dielectric fluid from the activating fluid actuation system through each first inlet to force each moving contact towards the second position to establish an electrically conductive pathway between the first and second stationary contacts, and is reset by introducing pressurised dielectric fluid from the resetting fluid actuation system through each second inlet to force each moving contact back towards the first position where each moving contact is not in contact with the first stationary contact and the electrically conductive pathway between the first and second stationary contacts is broken.

[0033] The resetting fluid actuation system is fluidly connected to each second inlet. The requirements for resetting each moving contact are far less stringent than those for activating and thus the fluid containment may be far more compliant. But the resetting fluid actuation system is preferably designed to minimise back-pressure which might hinder activation performance. The resetting accumulators at each end of series-connected arcing contact modules in an open to protect arrangement may optionally have smaller capacity than the intermediate resetting accumulator(s). In an arrangement where the circuit breaker includes a plurality of second inlets, each second inlet can include its own fluid actuation means that includes a resetting accumulator for storing the pressurised dielectric fluid, a release valve, and associated passageways. But fluid actuation means can also be shared by two or more second inlets. For example, the resetting fluid actuation system can include a single resetting accumulator that is connected to each second inlet, either by a single release valve or by a series of release valves (i.e., each second inlet has its own respective release valve). Each release valve is opened and closed under the control of a control unit, and can have any suitable construction. On receipt of a signal to reset the circuit breaker, each release valve is opened to allow the pressurised dielectric fluid in the associated resetting accumulator to flow through each second inlet and provide the fluid actuation that forces the moving contact(s) back to the first position. Where the resetting fluid actuation system includes two or more release valves they can be controlled to open simultaneously to ensure synchronisation of the arcing contact modules, but absolute timing precision is not essential for circuit breaker resetting.

[0034] It will be readily appreciated that any dielectric fluid on the second inlet-side of each moving contact must be displaced through the second inlet during activation of the circuit breaker (i.e., the dielectric fluid is displaced as each moving contact moves from the first position towards the second position). The resetting fluid actuation system therefore preferably includes at least one drain valve that allows the dielectric fluid to be displaced through the associated fluid actuation means fluidly connected to each second inlet. Pressurised dielectric fluid will flow from each resetting accumulator into the linear passageway through the associated second inlet(s) during circuit breaker resetting and displaced dielectric fluid will flow out of the linear passageway through the second inlet(s) during circuit breaker activation.

[0035] The displaced dielectric fluid during circuit breaker activation will typically flow through each drain valve into a drain system. But at least a portion of the displaced dielectric fluid can be allowed to flow through each suitably adapted release valve to pressurise the resetting accumulator(s). When the circuit breaker is activated for protection purposes, each drain valve in the resetting fluid actuation system is typically opened substantially simultaneously with each release valve in the activating fluid actuation system to allow for the displacement of the dielectric fluid on the second inlet-side of each moving contact to flow into an un-pressurised receiver of the drain system as a result of moving contact movement.

[0036] It will also be readily appreciated that any dielectric fluid on the first inlet-side of each moving contact must be displaced during resetting of the circuit breaker (i.e., the dielectric fluid is displaced as each moving contact moves from the second position back towards the first position). The activating fluid actuation system therefore preferably includes at least one drain valve that allows the dielectric fluid to be displaced through the associated fluid actuation means. Pressurised dielectric fluid will flow from each activating accumulator into the linear passageway through the associated first inlet(s) during circuit breaker activation and displaced dielectric fluid will flow out of the linear passageway through the first inlet(s) during circuit breaker resetting.

[0037] The displaced dielectric fluid during circuit breaker resetting will typically flow through each drain valve into a drain system. A common drain system for both the activating and resetting fluid actuation systems can be used. But at least a portion of the displaced dielectric fluid can be allowed to flow through each suitably adapted release valve to pressurise the activating accumulator(s). When the circuit breaker is reset, each drain valve in the activating fluid actuation system is therefore opened substantially simultaneously with each release valve in the resetting fluid actuation system to allow for the displacement of the dielectric fluid on the first inlet-side of each moving contact to flow into the drain system as a result of moving contact motion. The displaced dielectric fluid flowing through the various drain valves can be collected by a common un-pressurised receiver that can be the main holding tank for the dielectric fluid. Dielectric fluid in the un-pressurised receiver can be pumped into a pressurised receiver that forms part of a vent system (see below). Each arcing contact module can have its own drain system, or a common drain system for a plurality of arcing contact modules can be provided.

[0038] During the activation process, each moving contact attains a high velocity and this may be moderated to some extent by defining that the energy that is stored in the activating accumulator(s) is significantly dissipated during the initial acceleration of each moving contact thereby avoiding the attainment of a needlessly high velocity at end of stroke. As has already been mentioned, in an open to protect arrangement, the activating accumulator(s) are not always the sole source of actuating pressure once arcing has been initiated between moving and stationary contacts. Each moving contact is preferably brought to rest at the end of its activating stroke and suitable stopping means, e.g., a rebound damper, can be provided. Similarly, each moving contact is preferably brought to rest at the end of its resetting stroke and suitable stopping means, e.g., a rebound damper, can be provided.

[0039] Each outlet can optionally be configured as an annular vent. When each moving contact separates from the surrounding first stationary contact in an open to protect arrangement, an arc is rapidly established across the outlet between the adjacent first and second stationary contacts. The movement of each moving contact towards the second position places each outlet in direct fluid communication with the associated first inlet (i.e., the moving contact is no longer interposed between them in the linear passageway) and the pressurised dielectric fluid from the activating accumulator(s) flows into the linear passageway through each first inlet and out of the linear passageway through the associated outlet(s). In one arrangement where the pressurised dielectric fluid is a liquid and where the liquid decomposes into a liquid/gas mixture, a liquid/gas mixture is blasted through each outlet and displaces the established arc into the surrounding annular vent whose outer extremity can be in the form of an annular space between two opposing flanges. The annular space can have a vent opening that communicates with a vent chamber. The dielectric fluid or liquid/gas mixture can flow radially outwardly through the annular vent and then linearly through the vent chamber.

[0040] The fast-flowing and pressurised dielectric fluid serves to extinguish the arc by removing the heat that would otherwise sustain the ionisation process within the arc and maintain its electrically conductive state. In one arrangement, where the dielectric fluid is a liquid, some of the dielectric decomposes as a result of receiving heat from the arc and the preferred liquids decompose to form a highly pressurised dielectric gas bubble with a high heat diffusion rate that surrounds the arc. Heat is removed from the arc by a combination of conduction, forced convection and radiation processes that are effective from arc initiation between the moving and first stationary contacts until the arc is displaced by the pressurised dielectric fluid into the annular vent. An undesirable but inevitable effect of arcing is that small particles of carbon and metal will be sparsely dispersed within the fluid or liquid/gas mixture that flows through the annular vents. The volumetric flow rate of fluid and the relatively low concentration of entrained gas and particles is such that these pollutants have a tolerable small effect on the current breaking and transient voltage withstand capability of the circuit breaker. Nevertheless, these pollutants must not be permitted to accumulate in an uncontrolled manner and their removal from the fluid circuit is described below. It is also inevitable that a small proportion of the gaseous products of decomposition are dissolved in the dielectric fluid and these have minimal effect on circuit breaker performance providing they are not allowed to accumulate in an uncontrolled manner. In accordance with best practice, the condition of the dielectric fluid must be analysed periodically and the fluid must be replaced if necessary. The arc-facing surfaces of each annular vent and vent chamber can be constructed using any convenient insulation material and preferably benefit from ablation protection as used in known HVAC circuit breakers. Each vent chamber is preferably fluidly connected to a pressurised vent system that is maintained at a pressure that is preferably above atmospheric pressure and is typically less than 10% of the activating (or opening) accumulator pressure. In one arrangement, pressure is preferably applied to the vent system in order to increase the dielectric strength of any entrained gas within the liquid/gas mixture that is blasted through each outlet in order to eliminate the risk of voltage breakdown and re-strike after current interruption. Pressure is also preferably applied to the vent system so that a defined retaining force is applied to each moving contact to retain it in the open position. Mechanical retainers can also be used but the use of fluid pressure is normally preferable. Each arcing contact module can have its own vent system, or a common vent system for a plurality of arcing contact modules can be provided.

[0041] The construction and/or arrangement of outlets/vents etc. in a close to protect arrangement can be different from an open to protect arrangement because there is not normally any need to interrupt significant (if any) fault current.

[0042] The present invention further provides a method of operating a circuit breaker comprising at least one arcing contact module, each arcing contact module comprising:

a first dielectric fluid inlet;
a first stationary contact;
a second stationary contact, the first and second stationary contacts being spaced apart by a gap that defines a dielectric fluid outlet; and
a moving contact;
the method comprising the steps of:

on receipt of a signal to activate the circuit breaker, introducing pressurised dielectric fluid through the first inlet to move the moving contact from:

(a) a first position (e.g., where for an open to protect arrangement the moving contact is in electrical contact with the first and second stationary contacts to provide an electrically conductive pathway between the first and second stationary contacts), to
(b) a second position (e.g., where for an open to protect arrangement the moving contact is not in electrical contact with the first stationary contact, thereby establishing an arc across the gap between the first and second stationary contacts, and wherein the introduced pressurised dielectric fluid flows through the outlet to cool the arc).

[0043] In one arrangement, dielectric fluid can be circulated through the circuit breaker (e.g., through the linear passageway) for a pre-determined period after circuit breaker opening, and optionally on a continuous basis until it is required that the circuit breaker is reset to permit re-activation for protection purposes. This ensures that entrained gas and particulate pollutants are purged from the arcing and vent chambers to the vent system.

[0044] The vent system can be pressurised by a pump with any convenient form of pressure regulation. The vent system can include a pressurised receiver that receives the dielectric fluid from each outlet. The pump inlet can be connected to the unpressurised receiver of the drain system. In other words, dielectric fluid in the unpressurised receiver of the drain system can be pumped into the pressurised receiver of the vent system. The vent system can be out-gassed by any convenient means and this out-gassing may be facilitated by a pumped system. In some arrangements (e.g., LV and MV systems where arc energy and arc voltage are lower) out-gassing may be less important but for all open to protect arrangements, dielectric fluid flow will typically always be required to continue for a period of time after activation of the circuit breaker to help extinguish the arc and flush products of thermal decomposition away from the moving contacts in order to reduce the risk of re-strike. Particulate pollutants are preferably filtered out of the dielectric fluid. The out-gassed dielectric fluid from the pressurised receiver can be pumped by at least one positive displacement pump in order to achieve accumulator pressurisation. In other words, the vent system preferably forms part of a closed-loop system where out-gassed dielectric fluid is returned to each accumulator or circulated through the linear passageway. The at least one pump can run continuously until accumulators attain their desired working pressure and also for a defined period as previously described when the circuit breaker is activated, and optionally may run continuously. Any convenient form of pressure regulation may be employed. Separate pumps may be employed to pressurise respective activating and resetting accumulators when these have different operating pressures.

[0045] Non-return valves can be employed in any or all of the connections between the accumulator pressurisation feed or feeds and respective accumulators.

Open to protect arrangement - operating modes:

[0046] The circuit breaker having an open to protect arrangement has three modes of operation, namely an activation (or opening) mode, a holding mode, and a resetting (or closing) mode.

Opening mode:

[0047] Before receipt of a signal to open, each moving contact is in the first (or closed) position where it is in electrical contact with the surrounding first and second stationary contacts of the associated arcing contact module. On receipt of a signal to open, each release valve in the activating (or opening) fluid actuation system and each drain valve in the resetting (or closing) fluid actuation system is opened as described above. Pressurised dielectric fluid flows rapidly from each opening accumulator, through associated fluid actuation means, and into the linear passageway where it provides fluid actuation to force each moving contact towards the second (or open) position.

[0048] As each moving contact is forced towards the open position, dielectric fluid on the second-inlet side is forced out of the linear passageway through each second inlet and through the associated fluid actuation means of the closing fluid actuation system to the un-pressurised receiver of the drain system. Each closing accumulator can also be pressurised if flow is allowed through the release valve(s) of the closing fluid actuation system. The displacement of dielectric fluid into the un-pressurised receiver substantially stops once each moving contact reaches the open position. But in practice it is possible for there to be a small amount of leakage of pressurised dielectric fluid past each moving contact when in the open position.

[0049] With initial separation, an arc is established between each moving contact and the adjacent end of the first stationary contact. Further movement of each moving contact towards the open position causes an arc to be established across each outlet between the associated first and second stationary contacts. The pressurised dielectric fluid flows out of the linear passageway through each outlet where it cools the associated arc and promotes current interruption. The pressurised dielectric fluid flows out of the vent chamber to the pressurised receiver of the vent system.

Holding mode:

[0050] After current interruption has taken place, dielectric fluid can be circulated through the linear passageway, the outlets, and then to the pressurised receiver of the vent system to ensure out-gassing and to temporarily retain each moving contact in the open position. During this temporary phase of the holding mode it is the pressure within the pressurised receiver that defines the retaining force on the moving contact(s); it being the case that the pressure within the pressurised receiver is typically greater than that in the un-pressurised receiver. Also during this temporary phase of the holding mode the opening accumulator pressure continues to reduce until it becomes asymptotic with the pressure that is maintained in the pressurised receiver.

[0051] A small amount of dielectric fluid may leak past the moving contact(s) and into the un-pressurised receiver through the second inlets. Dielectric fluid in the un-pressurised receiver of the drain system can be pumped into the pressurised receiver so that the fluid flow in the temporary phase of the holding mode can be sustained for as long as desired. At the end of the temporary phase, the opening accumulator pressure would be insufficient to allow the circuit breaker to be opened again should it be closed for any reason.

[0052] Opening accumulator pressure should be within normal operating limits and the circuit breaker should be capable of re-opening before the moving contact is returned to the closed position. The closing release valves must therefore be closed for a period of time that is sufficient to allow re-pressurisation of each opening accumulator prior to activating a closing mode. In this final phase of the holding mode, it is the pressure within the pressurised receiver of the vent system that continues to define the retaining force on each moving contact. A small amount of dielectric fluid may continue to leak past the moving contact(s) and into the unpressurised receiver and thus the fluid flow in each outlet may reverse. Since the dielectric fluid in the pressurised receiver is out-gassed and flow through each outlet is minimal, gas entrainment in the reversed flow is insignificant, i.e., an insignificant amount of gas in introduced within the outlet(s). Dielectric fluid in the un-pressurised receiver of the drain system can be pumped back into the pressurised receiver such that the fluid flow in the final phase of the holding mode can be sustained for as long as desired. At the end of this final phase, the opening accumulator pressure is once again sufficient to allow the circuit breaker to be opened again.

Closing mode:

[0053] On receipt of a signal to close, each release valve in the closing fluid actuation system and each drain valve in the opening fluid actuation system is opened as described above. Pressurised dielectric fluid flows from each closing accumulator, through associated fluid actuation means and into the linear passageway where it provides fluid actuation to force each moving contact towards the closed position.

[0054] As each moving contact is forced towards the closed position, dielectric fluid on the first-inlet side is initially forced out of the each outlet and also out of the linear passageway through each first inlet and through the associated fluid actuation means of the opening fluid actuation system to the un-pressurised receiver of the drain system. As each moving contact approaches the respective first stationary contact, the initial component of fluid flow through each outlet becomes restricted by the reducing opening cross sectional area and eventually stops. The fluid flow is then entirely forced to flow out of the linear passageway through each first inlet and through the associated fluid actuation means of the opening fluid actuation system to the unpressurised receiver of the drain system.

[0055] Each opening accumulator can also be pressurised as a result of the contact motion and consequent displacement of fluid from the linear passageway. The displacement of dielectric fluid into the un-pressurised receiver substantially ceases once each moving contact reaches the closed position.

Close to protect arrangement - operating modes:

[0056] The circuit breaker having a close to protect arrangement has three modes of operation, namely an activation (or closing) mode, a holding mode, and a resetting (or opening) mode.

Closing mode:

[0057] Before receipt of a signal to close, each moving contact is in the first (or open) position where it is not in electrical contact with the first stationary contact of the associated arcing contact module. On receipt of a signal to close, each release valve in the activating (or closing) fluid actuation system and each drain valve in the resetting (or opening) fluid actuation system is opened as described above. Pressurised dielectric fluid flows rapidly from each closing accumulator, through associated fluid actuation means, and into the linear passageway where it provides fluid actuation to force each moving contact towards the closed position where the moving contact is in contact with both the first and second stationary contacts and fault current is diverted by external circuit lines to a ground connection, for example.

[0058] As each moving contact is forced towards the second (or closed) position, dielectric fluid on the second-inlet side is forced out of the linear passageway through each second inlet and through the associated fluid actuation means of the opening fluid actuation system to the un-pressurised receiver of the drain system. Each opening accumulator can also be pressurised as a result of the contact motion and consequent displacement of fluid from the linear passageway if flow is allowed through the release valve(s) of the opening fluid actuation system. The displacement of dielectric fluid into the un-pressurised receiver substantially stops once each moving contact reaches the closed position. But in practice it is possible for there to be a small amount of leakage of pressurised dielectric fluid past each moving contact when in the closed position.

[0059] The displaced dielectric fluid also flows out of the linear passageway through each outlet during the initial phase of contact motion which ends when the moving contact enters the first stationary contact. The displaced dielectric fluid flows out of the vent chamber to the pressurised receiver of the vent system.

[0060] After each moving contact has reached the closed position, it is retained in the closed position by the continuous application of pressure from the closing accumulator. A small amount of dielectric fluid may continue to leak past the moving contact.

[0061] Closing accumulator pressure should be within normal operating limits and the circuit breaker should be capable of re-closing before the moving contact is returned to the open position. The closing release valves must therefore be closed for a period of time that is sufficient to allow re-pressurisation of each closing accumulator prior to activating an opening mode.

Opening mode:

[0062] On receipt of a signal to open, and subject to the above requirement for the circuit breaker to have regained the ability to re-close before opening may be initiated, each release valve in the opening fluid actuation system and each drain valve in the closing fluid actuation system is opened as described above. Pressurised dielectric fluid flows from each opening accumulator, through associated fluid actuation means and into the linear passageway where it provides fluid actuation to force each moving contact towards the open position.

[0063] As each moving contact is forced towards the open position, dielectric fluid on the second-inlet side is forced out of the linear passageway through each first inlet and through the associated fluid actuation means of the closing fluid actuation system to the un-pressurised receiver of the drain system. Each closing accumulator can also be pressurised as a result of the contact motion and consequent displacement of fluid from the linear passageway if flow is allowed through the release valve(s) of the closing fluid actuation system. The displacement of dielectric fluid into the unpressurised receiver substantially stops once each moving contact reaches the open position. But in practice it is possible for there to be a small amount of leakage of pressurised dielectric fluid past each moving contact when in the open position.

[0064] With initial separation, an arc is established between each moving contact and the adjacent end of the first stationary contact if current is flowing prior to initial separation. Further movement of each moving contact towards the open position may cause an arc to be established across each outlet between the associated first and second stationary contacts if current is sufficiently great but under normal circumstances the initial arc will be extinguished rapidly and without being established between the associated first and second stationary contacts. The pressurised dielectric fluid flows out of the linear passageway through each outlet where it cools the associated arc and promotes current interruption. The pressurised dielectric fluid flows out of the vent chamber to the pressurised receiver of the vent system.

Holding mode:

[0065] After current interruption has taken place, dielectric fluid can be circulated through the linear passageway, the outlets, and then to the pressurised receiver of the vent system to ensure out-gassing and to temporarily retain each moving contact in the open position. During this temporary phase of the holding mode it is the pressure within the pressurised receiver that defines the retaining force on the moving contact(s); it being the case that the pressure within the pressurised receiver is typically greater than that in the un-pressurised receiver. Also during this temporary phase of the holding mode the opening accumulator pressure continues to reduce until it becomes asymptotic with the pressure that is maintained in the pressurised receiver. A small amount of dielectric fluid may leak past the moving contact(s) and into the un-pressurised receiver through the second inlets. Dielectric fluid in the unpressurised receiver of the drain system can be pumped into the pressurised receiver so that the fluid flow in the temporary phase of the holding mode can be sustained for as long as desired. At the end of the temporary phase, the opening accumulator pressure would be insufficient to allow the circuit breaker to be opened again should it be closed for any reason.

[0066] The circuit breaker can use any suitable dielectric fluid, e.g., a proprietary liquid dielectric oil such as MIDEL, or a gas. Preferred dielectric liquids are preferably incompressible, and have a high heat capacity and gaseous products of decomposition that predominantly comprise hydrogen. The dielectric liquid preferably has sufficient viscosity to provide beneficial lubrication to sliding interfaces and to resist leakage past the same. Many proprietary synthetic esters and refined natural esters have been developed for use as transformer oil for use in tap changers and other switch applications and would be suitable.

[0067] It will be readily understood that, for an open to protect arrangement, the dynamic behaviour of the moving contacts and the established arcs will preferably be substantially equal, and that the total arc voltage and rate of heat transfer and total heat capacity will preferably be substantially *pro-rata* with the number of moving contacts that are connected in series. The total 'off' state voltage, transient recovery voltage and rate of rise of transient recovery voltage capability of the moving contacts should ideally be substantially *pro-rata* with the number of moving contacts that are connected in series and it is preferable that conventional voltage balancing means are employed. These voltage balancing means may be connected in parallel with respective first and second stationary contacts, i.e., in parallel with each switch contact system in a string of series connected switch contact systems. Although it is possible for the opening behaviour of the closed to protect arrangement to be enhanced by the provision of such voltage balancing and also the use of surge arresters or by hybridisation with a switching aid network (or snubber), it is not generally preferred that this enhancement is performed.

[0068] The circuit breaker can be used in conjunction with at least one surge arrester whose functions are to define the maximum voltage that is experienced by the series-connected moving contacts, and to dissipate the majority of the inductively stored energy in the dc or ac circuit. It will be understood that the above-defined rapid development of total arc voltage is beneficial in speeding up the commutation of current from circuit breaker into the surge arrester and consequently reducing the proportion of inductively stored energy that is dissipated within the circuit breaker. It will also be understood that the greater the initial rate of heat transfer between arcs and their surrounding medium, the lower the total heat transfer between arcs and their surrounding medium. The circuit breaker may be hybridised with any convenient form of switching aid network (or 'snubber') wherein current is at least partially commutated from the circuit breaker into the switching aid network before the voltage in the series connected contacts attains a voltage that is sufficient to cause final commutation into the surge arrester in order to further reduce the total heat transfer between arcs and their surrounding dielectric fluid.

[0069] The circuit breaker can be hermetically sealed insofar as it is filled with a dielectric fluid that is highly pressurised during activation and remains filled and lightly pressurised after activation. As a result of this internal pressurisation, there is no risk of ingress of dust or moisture or other pollutants. The circuit breaker is inherently well suited to use in heavily polluted environments as long as its external enclosure is suitable sealed and has adequate clearance and creepage dimensions etc.

[0070] The circuit breaker can be located within an externally pressurised environment, which can be a dielectric fluid. The surrounding dielectric fluid can be, for example, a process fluid that is associated with electrical system of which the circuit breaker forms a part. The surrounding dielectric fluid can be pressurised by another fluid from which it is segregated by a pressure-balanced enclosure. In one arrangement, the circuit breaker can be located within a dielectric liquid-filled housing that is immersed in sea water, the housing including a diaphragm or bellows or other suitable means of ensuring that the dielectric liquid is pressurised in accordance with the pressure and depth of the surrounding sea water. When operating in such an externally pressurised environment, the above described fluid actuation pressures must be maintained with respect to the pressure of the external environment, i.e., actuating differential pressures must be maintained and respective absolute pressures must be increased correspondingly with the external pressure and depth.

[0071] In the case of an ac circuit breaker having an open to protect arrangement, an arcing contact module can be connected between an incoming ac line and an outgoing ac line of an ac circuit (e.g., a single- or multi-phase ac circuit between a power supply and a load). In a single-phase, floating, open to protect arrangement, an arcing contact module can be provided in one or both of the ac lines. In the case of an ac circuit breaker having a close to protect arrangement, an arcing contact module can be connected between an ac line of an ac circuit (e.g., a single- or multi-phase ac circuit between a power supply and a load) and a ground connection, between two ac lines of an ac circuit, or between an ac line of an ac circuit and an interconnection point such that the ac lines are interconnected in either a star or delta configuration, for example.

[0072] In these multiphase ac circuit breaker configurations, it is necessary to provide insulation between each arcing contact module and this insulation must be adequate for the interphase voltage. Subject to satisfying this interphase insulation requirement, a number of arcing contact modules may be physically integrated and aligned along the same axis. It is equally applicable for a number of arcing contact modules to be arranged beside one another with their axes in a parallel relationship. Similar open to protect and closed to protect arrangements may also be used in dc systems and these would typically have either one or two lines. These dc systems would be schematically equivalent to single-phase ac systems.

[0073] In general terms, arcing contact modules can be combined and interconnected in a wide range of arrangements according to the power supply and load that the circuit breaker is intended to protect. Power supplies may be ground-referenced or floating and they may be ac or dc. Multi-phase ac power supplies may not always be provided with a neutral terminal, e.g., three-phase, three-line systems.

[0074] Power supply networks and loads may employ a wide range of ac and dc voltages and currents, maximum prospective fault voltages and currents, rates of increase of current and voltage etc., and the levels of inductively stored energy that must be dissipated as a consequence of current interruption may vary over a correspondingly wide range. The current, voltage and dissipation ratings of the arcing contact modules may be conveniently defined by appropriate choice of physical dimensions, operating pressures and flows. In order to achieve higher ratings than can conveniently be achieved by scaling alone, any convenient number of arcing contact modules may be combined in series, parallel and series-parallel interconnected networks. Arrangements with series connected arcing contact modules will generally be physically integrated into a circuit breaker where the moving contacts (or switch contacts) are aligned along a common axis. The moving contacts (or switch contacts) in parallel connected arcing contact modules may also be physically integrated into a circuit breaker where all the moving contacts are aligned along a common axis and where the parallel interconnection means takes the form of a number of external connections and links. The moving contacts in polyphase ac and multi-pole dc circuits may also be physically integrated into a circuit breaker where all the moving contacts are aligned along a common axis and where the associated stationary contacts are galvanically isolated from each other and are connected to suitable external terminals.

[0075] Figures 13A to 13Y show some possible ways in which the arcing contact modules can be combined and interconnected to define a circuit breaker according to the present invention. It will be readily appreciated that other combinations and interconnections are possible and will be known to the skilled person.

[0076] The arcing contact modules are located in the ac or dc circuit between a suitable power supply PS and a load L.

[0077] In each case, each individual arcing contact module is represented by a dashed box that contains at least one switch element representing a moving contact.

[0078] The different arrangements can be summarised as follows:

- Figure 13A shows a three-phase, ground-referenced, open to protect arrangement with an ac circuit.
- Figure 13B shows a three-phase, floating, open to protect arrangement with an ac circuit.
- Figure 13C shows a single-phase, ground-referenced, open to protect arrangement with an ac circuit.
- Figure 13D shows a single-phase, floating, open to protect arrangement with an ac circuit having a switch arrangement in only one of two ac lines.
- Figure 13E shows a single-phase, floating, open to protect arrangement with an ac circuit having a switch arrangement in each of two ac lines.
- Figure 13F shows a ground-referenced, open to protect arrangement with a dc circuit.
- Figure 13G shows a floating, open to protect arrangement with a dc circuit having a switch arrangement in only one of two dc lines.
- Figure 13H shows a floating, open to protect arrangement with a dc circuit having a switch arrangement in each of two dc lines.
- Figure 13I shows a three-phase, ground-referenced, close to protect arrangement with an ac circuit.
- Figure 13J shows a three-phase, floating, close to protect arrangement with a star-connected ac circuit.
- Figure 13K shows a three-phase, floating, close to protect arrangement with a delta-connected ac circuit.
- Figure 13L shows a single-phase, ground-referenced, close to protect arrangement with an ac circuit.
- Figure 13M shows a single-phase, floating, close to

protect arrangement with an ac circuit.

- Figure 13N shows a ground-referenced, close to protect arrangement with a dc circuit.
- Figure 13O shows a floating, close to protect arrangement with a dc circuit.
- Figure 13P shows a single-break switch module.
- Figure 13Q shows a double-break switch module having an inherent series connection.
- Figure 13R shows an assembly comprising two double-break switch modules having an inherent series connection.
- Figure 13S shows two single-break switch modules having an external parallel interconnection.
- Figure 13T shows two double-break switch modules, each having an inherent series connection, the two modules having an external parallel interconnection.
- Figure 13U shows a first assembly comprising two double-break switch modules having an inherent series connection, a second assembly comprising two double-break switch modules having an inherent series connection, the first and second assemblies having an external parallel interconnection.
- Figure 13V shows a double-break switch module having an inherent series connection and having external links that provide for parallel interconnection.
- Figure 13W shows an assembly comprising two double-break switch modules, each having an inherent series connection, and having external links that provide for parallel interconnection.
- Figure 13X shows an assembly comprising three electrically independent single-break switch modules.
- Figure 13Y shows three assemblies each comprising an electrically independent single-break switch module.

Drawings

[0079]

Figure 1 is a cross sectional view of an arcing contact module that forms part of a dc circuit breaker according to the present invention having an open to protect arrangement;

Figure 2A is a cross sectional view of a dc circuit breaker according to the present invention in a closed position having an open to protect arrangement;

Figure 2B is a cross sectional view of the circuit breaker of Figure 2A in an opening position, i.e., during circuit breaker opening;

Figure 2C is a cross sectional view of the circuit breaker of Figure 2A in a fully open position;

Figure 3A is a schematic view of a dc circuit breaker according to the present invention showing external hydraulic components;

Figures 3B to 3E are schematic views of the circuit breaker of Figure 3A showing flow pathways of dielectric liquid through the circuit breaker during opening, holding and closing modes;

Figure 4 is a schematic view of a single-break ac circuit breaker according to the present invention having an open to protect arrangement;

Figure 5 is a schematic view of a double-break ac circuit breaker according to the present invention having an open to protect arrangement;

Figure 6 is a schematic view of a single-break ac circuit breaker according to the present invention having a close to protect arrangement;

Figure 7 is a cross sectional view of an arcing contact module that forms part of the ac circuit breaker of Figure 4;

Figure 8 is a schematic view of the arcing module of Figure 7 showing external hydraulic components

Figure 9 is a cross sectional view of an arcing contact module that forms part of the ac circuit breaker of Figure 5;

Figure 10 is a schematic view of the arcing contact module of Figure 9 showing external hydraulic components;

Figure 11 is a cross sectional view of the arcing contact module that forms part of the ac circuit breaker of Figure 6;

Figure 12 is a schematic view of the arcing contact module of Figure 11 showing external hydraulic components; and

Figures 13A to 13Y are schematic views of circuit breakers according to the present invention.

[0080] With reference to Figure 1, an arcing contact module 1b that forms part of a dc circuit breaker according to the present invention includes a first stationary contact 2 in the form of an electrically conductive tubular member with a radially outer support. A pair of second stationary contacts 4b, 4c in the form of electrically conductive tubular members with radially outer supports are coaxially aligned with the first stationary contact 2 and are spaced apart from first and second ends 2', 2" of the first stationary contact by respective annular gaps or vents 6 that define dielectric liquid (or gas/liquid) outlets. The radially outer part of each gap includes an annular vent opening 8 that communicates with an annular vent chamber 10. The arc-facing surfaces of the vents 6 and the vent chambers 10 can be constructed using any convenient insulation material and preferably benefit from ablation protection as used in HVAC circuit breakers.

[0081] The stationary contacts 2, 4b, 4c together define a linear passageway 12 in which a pair of moving contacts 14 are positioned. As explained herein, the interface between each moving contact 14 and the stationary contacts 2, 4b, 4c can include a hydraulic sealing region, an electrical sliding contact region and an arc erosion resistant region. Each moving contact 14 has a substantially cylindrical shape and preferably has a relatively low mass, the mass being minimised by providing an internal cavity. In one arrangement, each moving contact 14 has a lightweight aluminium alloy cylindrical body upon which a high electrical conductivity and wear-resistant layer is applied or deposited in order to facilitate a sliding contact mechanism, and has suitably profiled arc erosion-resistant arcing faces or contact tips. The moving contacts 14 are a close tolerance fit within the linear passageway 12 (i.e., within the radially inner cylindrical surfaces of the stationary contacts) so that leakage of dielectric liquid past the moving contacts is minimised.

[0082] An opening dielectric liquid inlet or port 16b is provided at the first stationary contact 2 and includes an opening 16b' in fluid communication with the linear passageway 12. Closing dielectric liquid inlets or ports 18b, 18c are provided at the second stationary contacts 4b, 4c and each closing inlet includes an opening 18b', 18c' in fluid communication with the linear passageway 12.

[0083] A hydraulic rebound damper arrangement 20 is provided at the first stationary contact 2, adjacent to the opening 16b' of the opening inlet 16b. A hydraulic rebound damper arrangement 22b, 22c is provided at each second stationary contact 4b, 4c adjacent the opening 18b', 18c' of each closing inlet 18b, 18c. The hydraulic rebound damper arrangements 20, 22c, 22d are designed to bring the moving contacts 14 to rest at the end of their opening and closing strokes as described in more detail below. Each hydraulic damper arrangement 20 that is adjacent to the opening 16b can include a pair of damper members arranged to contact a respective moving contact. Although the forces acting upon each damper member within a pair of damper members may be substantially equal and opposite, practical dimensional and performance tolerances may be such that pairs of damper members experience an axial force imbalance and hence each hydraulic rebound damper arrangement 20 is preferably appropriately secured within the linear passageway 12, e.g., using securing webs. Each hydraulic damper arrangement 22b, 22c, 22d, 22e is dedicated to the adjacent moving contact but pairs of hydraulic dampers 22b and 22c, 22d and 22e of adjacent arcing contact modules may be combined to give a hydraulic damper arrangement that includes a pair of damper members. When so combined, although the forces acting upon each damper member within a pair of damper members may be substantially equal and opposite, practical dimensional and performance tolerances may be such that pairs of damper members experience an axial force imbalance and hence each hydraulic rebound damper arrangement 22b, 22c and 22d, 22e is preferably appropriately secured within the linear passageway 12, e.g., using securing webs.

[0084] Each moving contact 14 can move axially within the linear passageway 12 between a pair of hydraulic rebound damper arrangements.

[0085] A dc circuit breaker may be constructed from a plurality of such arcing contact modules arranged in series, each being activated in a synchronous manner on receipt of a signal to open the dc circuit breaker. Exemplary circuit breaker 100 employs three such arcing contact modules 1a, 1b, 1c and for clarity, only part of two axially adjacent arcing contact modules 1a, 1c is shown. The arcing contact module 1b shares a second stationary contact 4b and a closing inlet 18b with arcing contact module 1a and its hydraulic damper arrangement 22c may be combined with adjacent hydraulic damper arrangement 22b as shown. The arcing contact module 1b shares a second stationary contact 4c and a closing inlet 18c with arcing contact module 1c and its hydraulic damper arrangement 22d may be combined with adjacent hydraulic damper arrangement 22e as shown. The number of arcing contact modules will be selected with reference to a desired arc voltage or total arcing performance. The dc circuit breaker 100 can employ shedded insulators around the stationary contacts 2, 4a, 4b, 4c, 4d and any structural supports for the various liquid conduits etc. Box-type corona shields with nominal curved edges can house other components such as the accumulators, valves and associated controls.

[0086] Figure 3A is a schematic representation of the dc circuit breaker 100 shown in Figure 1 but includes the various external hydraulic circuits. In order to permit convenient cross referencing to Figure 1, respective first stationary contacts are annotated 2a, 2b, 2c and respective second stationary contacts are annotated 4a, 4b, 4c, 4d. The dc circuit breaker 100 includes dc terminals 102, 104 and is connected to a dc network (not shown). A switching aid network or 'snubber' 106 is connected in parallel with the dc circuit breaker 100. The switching aid network 106 may comprise any convenient arrangement of passive and/or active components that serve to provide a path for current that is commutated out of the circuit breaker 100. The dc circuit breaker 100 includes three arcing contact modules 1a-1c with three opening inlets 16a-16c, four closing inlets 18a-18d, six vent chambers 10a-10f and six moving contacts. But it will be readily appreciated that the dc circuit breaker can include any suitable number of arcing contact modules. A first intermediate closing inlet 18b is shared between the first and second arcing contact modules 1a, 1b and a second intermediate closing inlet 18c is shared between the second and third arcing contact modules 1b, 1c.

[0087] An opening hydraulic actuation system includes a plurality of fast-acting hydraulic actuation means 24a-24c. Each hydraulic actuation means 24a-24c is fluidly connected to a respective opening inlet 16a-16c and includes an opening accumulator 26a-26c, an opening release valve 28a-28c, and a closing drain valve 30a-30c. In particular, each opening inlet 16a-16c is fluidly connected to its respective opening accumulator 26a-26c through the respective opening release valve 28a-28c and suitable liquid conduits (e.g., piping or tubing), and is fluidly connected to an unpressurised receiver 40 of a drain system through the respective closing drain valve 30a-30c and suitable liquid conduits.

[0088] A closing hydraulic actuation system includes a plurality of hydraulic actuation means 32a-32d. Each hydraulic actuation means is fluidly connected to a respective closing inlet 18a-18d and includes a closing accumulator 34a-34d, a closing release valve 36a-36d, and an opening drain valve 38a-38d. In particular, each closing inlet 18a-18d is fluidly connected to its respective closing accumulator 34a-34d through the respective closing release valve 36a-36d and suitable liquid conduits, and is fluidly connected to the un-pressurised receiver 40 through the respective opening drain valve 38a-38d and suitable liquid conduits. The end closing accumulators 34a, 34d can optionally have smaller capacity than the intermediate closing accumulators 34b, 34c that are fluidly connected to the intermediate closing inlets 18b, 18c.

[0089] The liquid conduits, valves, accumulators and all associated interconnections within a particular opening or closing hydraulic actuation system, and the interconnection between the system and the first stationary contact of the respective arcing contact module, can be electrically conductive and can conveniently be electrically connected to, and be housed within, an equi-potential shield. Associated control apparatus (not shown) can also be electrically connected to and housed within the equi-potential shield if desired. The equi-potential shield can act as a corona shield.

[0090] The un-pressurised receiver 40 is the main holding tank for the dielectric liquid (e.g., MIDEL).

[0091] The various release valves and drain valves are opened and closed under the control of a control unit (not shown).

[0092] The vent chambers 10a-10f are fluidly connected to a pressurised receiver 42 of a vent system by suitable liquid conduits that must be made of an electrically insulating material. The vent system is maintained at a pressure that is preferably above atmospheric pressure and is typically less than 10% of the opening accumulator pressure. The vent system is pressurised by a pump 44 with any convenient form of pressure regulation. The inlet of pump 44 is connected to the un-pressurised receiver 40 so that dielectric liquid in the un-pressurised receiver is pumped into the pressurised receiver 42.

[0093] The vent system is out-gassed by an out-gassing, drying and filtration means 46 that includes a pump 48. The dielectric liquid in the pressurised receiver 42 is generally maintained in a substantially gas- and particulate-free state but dielectric liquid that is recovered from vent chambers 10a-10f immediately following circuit breaker opening will contain finely entrained gas bubbles and particulates. These gas bubbles are preferably removed by the out-gassing means before the dielectric liquid is used by the opening and closing hydraulic actuation systems but a small gas content may be carried over into the opening hydraulic actuation systems and be re-circulated without adverse effect in practice. Several cycles of re-circulation may be needed before entrained gas bubbles are substantially removed. A desiccant or equivalent drying system can be used to remove moisture from the dielectric liquid and the entry of moisture is preferably minimised by sealing the fluid systems. Conventional replaceable paper cartridge or equivalent type filters can be connected in line with pump inlets.

[0094] Positive displacement pumps 50, 52 pump the out-gassed, dried and filtered dielectric liquid to the closing accumulators 34a-34d and the opening accumulators 26a-26c, respectively. Non-return valves (not shown) are employed in any or all of the liquid connections between the accumulator pressurisation feed or feeds and respective accumulators.

[0095] Figure 2A shows the dc circuit breaker 100 in a closed position. In particular, the moving contacts 14 of the arcing contact modules 1a-1c are in a closed position where each moving contact is in electrical contact with respective first and second stationary contacts 2, 4 to provide a continuous electrically conductive pathway between the dc terminals 102, 104 of the dc circuit breaker 100.

[0096] All arcing contact modules are controlled by a suitable control unit (not shown) that receives a signal to open the dc circuit breaker 100 for protection purposes when a fault current is developed, or in response to an operator request. On receipt of a signal to open the dc circuit breaker 100, the opening release valves 28a-28c in the opening hydraulic actuation system and the opening drain valves 38a-38d in the closing hydraulic actuation system are opened by the control unit (not shown). Pressurised dielectric liquid in the opening accumulators 26a-26c flows through the opening release valves 28a-28c and into the linear passageway 12 through the opening inlets 16a-16c to provide hydraulic actuation that forces the moving contacts 14 towards an open position. The moving contacts 14 are actuated simultaneously, with minimal delay and with rapidly increasing contact separation. Figure 2B shows an intermediate stage of dc circuit breaker opening where pressurised dielectric liquid flows through the opening inlets 16a-16c and where the moving contacts 14 are being forced by the pressurised dielectric liquid axially through the linear passageway 12 towards the opposing hydraulic damper arrangement 22. (In Figures 2B and 2C the flowpath of pressurised dielectric liquid is represented by faint solid arrows and in Figure 2B the movement direction of each moving contact 14 is represented by bold solid arrows.) As the moving contacts 14 move towards the open position, they will come out of electrical contact with the surrounding first stationary contacts 2. The electrically conductive pathway between the dc terminals 102, 104 of the dc circuit breaker 100 is broken at multiple locations (i.e., six in the illustrated arrangement where each arcing contact module 1a-1c has two moving contacts) and initial arcing is established between the moving contacts 14 and the first stationary contacts 2 as shown in Figure 2B. The action of the arcs that form as the moving contacts 14 separate from the first stationary contacts 2 causes thermal decomposition of the dielectric liquid and the resultant generation of gaseous products causes additional actuating pressure to be applied to the moving contacts. The moving contacts 14 are all actuated with substantially identical performance.

[0097] The dielectric liquid on the closing inlet-side of the moving contacts 14 must be displaced through the closing inlets 18a-18d during opening of the dc circuit breaker 100. Displaced dielectric liquid flows out of the linear passageway 12 through the closing inlets 18a-18d and suitable liquid conduits to the un-pressurised receiver 40. (In Figure 2B the flowpath of displaced dielectric liquid is represented by faint dashed arrows.)

[0098] As the moving contacts 14 continue to move towards the open position, arcing is rapidly established across the vents 6 between the adjacent first and second stationary contacts 2, 4. The pressurised dielectric liquid from the opening accumulators 26a-26c flows out of the linear passageway 12 through the vents 6. A liquid/gas mixture is therefore blasted through each annular vent 6 and displaces the established arcs into the surrounding vent chambers 10, rapidly removing heat and ionised material from the arcs in order to cause their extinction. As shown in Figures 2B and 2C, the dielectric liquid can flow radially outwardly through the vent openings 8 and then linearly through the vent chambers 10. From the vent chambers 10, the dielectric liquid flows through suitable liquid conduits to the pressurised receiver 42.

[0099] The moving contacts 14 are brought to rest at the end of their opening stroke (i.e., in an open position) by the opposing hydraulic damper arrangements 22a, 22b, 22c, 22d, 22e, 22f. Figure 2C shows the moving contacts 14 in the open position.

[0100] The flowpaths of dielectric liquid during circuit breaker opening are shown in Figure 3B.

[0101] Dielectric liquid can be circulated through the dc circuit breaker (e.g., through the linear passageway 12) for a pre-determined period after circuit breaker opening, and optionally on a continuous basis until the dc circuit breaker is ready to be closed. This ensures that entrained gas and other pollutants are purged from the arcing and vent chambers to the vent system. The circulating dielectric liquid benefits from out-gassing, drying and filtration. The rate of pollutant removal, in combination with the desired liquid purity, defines the pre-determined period during which the dielectric liquid is circulated through the dc circuit breaker. The circulating dielectric liquid can be used to apply a retention force to the moving contacts 14 to temporarily retain them in the open position until the dc circuit breaker 100 needs to be closed (or reset). In this holding mode, the dielectric liquid flows from the hydraulic actuation means 24a-24c of the opening hydraulic actuation system; out of the linear passageway 12 through the vents 6; and back to the pressurised receiver; the pressure that is present in the linear passageway 12 being defined by the pressure that is maintained in the pressurised receiver 42.. This retention force is applied to the moving contact 14 because the pressure in the pressured receiver 42 is greater than that in the unpressurised receiver 40. Dielectric liquid in the unpressurised receiver 40 of the drain system can be pumped into the pressurised vent receiver 42.

[0102] The opening accumulators 26a-26b are pressurised using the dielectric liquid in the pressurised receiver 42 with the pump 52 being operated to pump outgassed, dried and filtered dielectric liquid to the hydraulic actuation means.

[0103] The flowpaths of dielectric liquid during the temporary phase of the holding mode are shown in Figure 3C. During the temporary phase, any flow of dielectric liquid into the un-pressurised receiver 40 is minimal and is defined by leakage past the moving contacts 14.

[0104] During the final phase of the holding mode, the closing release valves 36a-36d must be closed for a period of time that is sufficient to allow re-pressurisation of each opening accumulator 26a-26c prior to circuit breaker closing. During this time, any circulation of dielectric liquid from the vent system is minimal and is defined by leakage past the moving contacts 14 as shown in Figure 3D.

[0105] On receipt of a signal to close the dc circuit breaker 100, an action that must be inhibited until the pressure in the opening accumulators 26a-26c and in the closing accumulators 34a-34d are within respective operation limits, this inhibition being performed by the control system (not shown), the closing release valves 36a-36d in the closing hydraulic actuation system and the closing drain valves 30a-30c in the opening hydraulic actuation system are opened by the control unit (not shown). Pressurised dielectric liquid in the closing accumulators 34a-34d flows through the closing release valves 36a-36d and into the linear passageway 12 through the closing inlets 18a-18d to provide hydraulic actuation that forces the moving contacts 14 back towards the closed position. The dielectric liquid on the opening inlet-side of the moving contacts 14 must be displaced through the opening inlets 16a-16c during closing of the dc circuit breaker 100. The displaced dielectric liquid initially flows out of the linear passageway 12 through the vents chambers 10a-10f and to the pressurised receiver 42 and also through the opening inlets 16a-16c to the unpressurised receiver 40. As the moving contacts 14 approach the first stationary contacts 2, the effective port area that is open to the vents reduces until it is closed. At this time, displaced dielectric liquid flows only out of the linear passageway 12 through the opening inlets 16a-16c and suitable liquid conduits to the un-pressurised receiver 40.

[0106] The moving contacts 14 are brought to rest at the end of their closing stroke (i.e., in the closed position shown in Figure 2A) by the opposing hydraulic damper arrangements 20.

[0107] It will be readily appreciated that other, non-hydraulic means (e.g., mechanical means) can also be used for circuit breaker closing.

[0108] The flowpaths of dielectric liquid during circuit breaker closing are shown in Figure 3E.

[0109] Figures 4 to 6 show different ac circuit breakers. In particular, Figure 4 shows a single-break ac circuit breaker 200 that is located in the ac circuit between a power supply PS and a load L. The ac circuit is a three-phase circuit and the circuit breaker includes an arcing contact module 202a-202c in each of the three ac lines 204a-204c.

[0110] In other words, the arcing contact modules 202a-202c are arranged in parallel. Each arcing contact module 202a-202c includes a single moving contact (represented in Figure 4 as a switch element) as described in more detail below. The arcing contact modules 202a-202c are controlled by a control unit 206 that receives a signal to activate the circuit breaker 200 for protection purposes when a fault current is developed, or in response to an operator request.

[0111] Figure 5 shows a double-break ac circuit breaker 300 that is similarly located in the three-phase ac circuit between a power supply PS and a load L. The circuit breaker includes an arcing contact module 302a-302c in each of the three ac lines 304a-304c.

[0112] Each arcing contact module 302a-302c includes a pair of moving contacts (represented in Figure 5 as a pair of series switch elements) as described in more detail below. The arcing contact modules 302a-302c are controlled by a control unit 306 that receives a signal to activate the circuit breaker 300 for protection purposes when a fault current is developed, or in response to an operator request.

[0113] The ac circuit breakers shown in Figures 4 and 5 are both open to protect arrangements, i.e., where each moving contact is moved to an open position on circuit breaker activation to prevent fault current flowing between the power supply PS and the load L, irrespective of whether the fault is symmetrically or asymmetrically disposed between ac lines or between ac lines and ground (Gnd). In contrast, the ac circuit breaker 400 shown in Figure 6 is a close to protect arrangement, i.e., where the moving contacts of each arcing contact module 402a-402c are moved to a closed position on circuit breaker activation to divert fault current to a ground connection 406, it being a requirement that this fault current is interrupted by other means. The ac circuit breaker 400 of Figure 6 has three arcing contact modules 402a-402c, each being connected between a respective ac line 404a-404c of the three-phase ac circuit and the ground connection 406. The arcing contact modules 402a-402c are controlled by a control unit 408 that receives a signal to activate the circuit breaker 400 for protection purposes when a fault current is developed, or in response to an operator request.

[0114] With reference to Figure 7, an arcing contact module 202 that forms part of the ac circuit breaker 200 includes a first stationary contact 208 in the form of an electrically conductive tubular member with a radially outer support. A second stationary contact 210 in the form of an electrically conductive tubular member with a radially outer support is coaxially aligned with the first stationary contact 208 and is spaced apart from the first stationary contact by an annular gap or vent 212 that defines a dielectric liquid (or gas/liquid) outlet. The radially outer part of each gap includes an annular vent opening 214 that communicates with an annular vent chamber 216. The arc-facing surfaces of the vents 214 and the vent chambers 216 can be constructed using any convenient insulation material and preferably benefit from ablation protection as used in known HVAC circuit breakers.

[0115] The stationary contacts 208, 210 together define a linear passageway 218 in which a moving contact 220 is positioned. As explained herein, the interface between each moving contact 220 and the stationary contacts 208, 210 can include a hydraulic sealing region, an electrical sliding contact region and an arc erosion resistant region. The moving contact 220 has a substantially cylindrical shape and preferably has a relatively low mass, the mass being minimised by providing an internal cavity. In one arrangement, the moving contact 220 has a lightweight aluminium alloy cylindrical body upon which a high electrical conductivity and wear-resistant layer is applied or deposited in order to facilitate a sliding contact mechanism, and has suitably profiled arc erosion-resistant arcing faces or contact tips. The moving contact 220 is a close tolerance fit within the linear passageway 218 (i.e., within the radially inner cylindrical surfaces of the stationary contacts) so that leakage of dielectric liquid past the moving contact is minimised.

[0116] An opening dielectric liquid inlet or port 222 is provided at the first stationary contact 208 and includes an opening 222' in fluid communication with the linear passageway 218. A closing dielectric liquid inlet or port 224 is provided at the second stationary contact 210 and includes an opening 224' in fluid communication with the linear passageway 218.

[0117] A hydraulic rebound damper arrangement 226 is provided at the first stationary contact 208, adjacent to the opening 222' of the opening inlet 222. A hydraulic rebound damper arrangement 228 is provided at the second stationary contact 210 adjacent the opening 224' of each closing inlet 224. The hydraulic rebound damper arrangements 226, 228 are designed to bring the moving contact 220 to rest at the end of its opening and closing stroke as described in more detail herein. Each hydraulic rebound damper arrangement 226, 228 is preferably appropriately secured within the linear passageway 218, e.g., using securing webs or to an end wall of the linear passageway.

[0118] The moving contact 220 can move axially within the linear passageway 218 between the hydraulic rebound damper arrangements 226, 228.

[0119] Figure 8 is a schematic representation of the arcing contact module 202 shown in Figure 7 but includes the various external hydraulic circuits. The arcing contact module 202 is located in one of the ac lines shown in Figure 4 and includes ac terminals 230, 232 that are connected to the power supply PS and load L.

[0120] An opening hydraulic actuation system includes a fast-acting hydraulic actuation means 234 that is fluidly connected to the opening inlet 222 and includes an opening accumulator 236, an opening release valve 238, and a closing drain valve 240. The opening inlet 222 is fluidly connected to the opening accumulator 236 through the opening release valve 238 and suitable liquid conduits (e.g., piping or tubing), and is fluidly connected to an unpressurised receiver of a drain system (not shown) through the respective closing drain valve 240 and suitable liquid conduits. Each arcing contact module can have its own drain system, or a common drain system can be shared between the arcing contact modules 202a-202c of the ac circuit breaker 200.

[0121] A closing hydraulic actuation system includes a hydraulic actuation means 242. The hydraulic actuation means 242 is fluidly connected to the closing inlet 224 and includes a closing accumulator 244, a closing release valve 246, and an opening drain valve 248. The closing inlet 224 is fluidly connected to the closing accumulator 244 through the closing release valve 246 and suitable liquid conduits, and is fluidly connected to the un-pressurised receiver (not shown) through the respective opening drain valve 248 and suitable liquid conduits.

[0122] The vent chamber 216 is fluidly connected to a pressurised receiver of a vent system (not shown) by suitable liquid conduits that must be made of an electrically insulating material. Each arcing contact module 202a-202c can have its own vent system, or a common vent system can be shared between the arcing contact modules of the ac circuit breaker 200.

[0123] With reference to Figure 9, an arcing contact module 302 that forms part of the ac circuit breaker 300 includes a first stationary contact 308 in the form of an electrically conductive tubular member with a radially outer support. A pair of second stationary contacts 310 in the form of electrically conductive tubular members with radially outer supports are coaxially aligned with the first stationary contact 306 and are spaced apart from first and second ends of the first stationary contact by respective annular gaps or vents 312 that define dielectric liquid (or gas/liquid) outlets. The radially outer part of each gap includes an annular vent opening 314 that communicates with an annular vent chamber 316. The arc-facing surfaces of the vents 314 and the vent chambers 316 can be constructed using any convenient insulation material and preferably benefit from ablation protection as used in known HVAC circuit breakers.

[0124] The stationary contacts 308, 310 together define a linear passageway 318 in which a pair of moving contacts 320 are positioned. As explained herein, the interface between each moving contact 320 and the stationary contacts 308, 310 can include a hydraulic sealing region, an electrical sliding contact region and an arc erosion resistant region. Each moving contact 320 has a substantially cylindrical shape and preferably has a relatively low mass, the mass being minimised by providing an internal cavity. In one arrangement, each moving contact 320 has a lightweight aluminium alloy cylindrical body upon which a high electrical conductivity and wear-resistant layer is applied or deposited in order to facilitate a sliding contact mechanism, and has suitably profiled arc erosion-resistant arcing faces or contact tips. The moving contacts 320 are a close tolerance fit within the linear passageway 318 (i.e., within the radially inner cylindrical surfaces of the stationary contacts) so that leakage of dielectric liquid past the moving contacts is minimised.

[0125] An opening dielectric liquid inlet or port 322 is provided at the first stationary contact 308 and includes an opening 322' in fluid communication with the linear passageway 318. Closing dielectric liquid inlets or ports 324 are provided at the second stationary contacts 310 and each closing inlet includes an opening 324' in fluid communication with the linear passageway 318.

[0126] A hydraulic rebound damper arrangement 326 is provided at the first stationary contact 308, adjacent to the opening 322' of the opening inlet 322. A hydraulic rebound damper arrangement 328 is provided at each second stationary contact 310 adjacent the opening 324' of each closing inlet 324. The hydraulic rebound damper arrangements 324, 326 are designed to bring the moving contacts 320 to rest at the end of their opening and closing strokes as described in more detail herein. The hydraulic damper arrangement 326 can include a pair of damper members arranged to contact a respective moving contact. Although the forces acting upon each damper member within a pair of damper members may be substantially equal and opposite, practical dimensional and performance tolerances may be such that pairs of damper members experience an axial force imbalance and hence each hydraulic rebound damper arrangement 326, 328 is preferably appropriately secured within the linear passageway 318, e.g., using securing webs or to an end wall of the linear passageway.

[0127] Each moving contact 320 can move axially within the linear passageway 318 between a pair of hydraulic rebound damper arrangements.

[0128] Figure 10 is a schematic representation of the arcing contact module 302 shown in Figure 9 but includes the various external hydraulic circuits. The arcing contact module 302 is located in one of the ac lines shown in Figure 5 and includes ac terminals 330, 332 that are connected to the power supply PS and load L.

[0129] An opening hydraulic actuation system includes a fast-acting hydraulic actuation means 334 that is fluidly connected to the opening inlet 322 and includes an opening accumulator 336, an opening release valve 338, and a closing drain valve 340. The opening inlet 322 is fluidly connected to the opening accumulator 336 through the opening release valve 338 and suitable liquid conduits (e.g., piping or tubing), and is fluidly connected to an unpressurised receiver of a drain system (not shown) through the respective closing drain valve 340 and suitable liquid conduits. Each arcing contact module 302a-302c can have its own drain system, or a common drain system can be shared between the arcing contact modules of the ac circuit breaker 300.

[0130] A closing hydraulic actuation system includes a hydraulic actuation means 342. The hydraulic actuation means 342 is fluidly connected to the closing inlets 324 and includes a closing accumulator 344, a closing release valve 346, and an opening drain valve 348. The closing inlets 324 are fluidly connected to the closing accumulator 344 through the closing release valve 346 and suitable liquid conduits, and are fluidly connected to the un-pressurised receiver (not shown) through the respective opening drain valve 348 and suitable liquid conduits. In an alternative arrangement, each closing inlet can have its own hydraulic actuation means, i.e., connected to its own closing accumulator.

[0131] The vent chambers 316 are fluidly connected to a pressurised receiver of a vent system (not shown) by suitable liquid conduits that must be made of an electrically insulating material. Each arcing contact module can have its own vent system, or a common vent system can be shared between the arcing contact modules of the ac circuit breaker.

[0132] Other features of the arcing contact modules 202, 302 that are not specific to ac requirements (e.g., use of shedded insulators and box-type corona shields, the operation and construction of the release valves, the receiver and vent systems etc.) are generally as described above for the dc circuit breaker.

[0133] The arcing contact modules 202, 302 for the ac circuit breakers 200, 300 are also operated in the same manner as the dc circuit breaker, with each moving contact initially being in a closed position in electrical contact with respective first and second stationary contacts to provide a continuous electrically conductive pathway between the ac terminals of each arcing contact module. All arcing contact modules 202a-202c, 302a-302c are controlled by the control unit 206, 306 that receives a signal to open the ac circuit breaker 200, 300 for protection purposes when a fault current is developed, or in response to an operator request. On receipt of a signal to open the ac circuit breaker 200, 300, the opening release valve 238, 338 in the opening hydraulic actuation system 234, 334 and the opening drain valve 246, 346 in the closing hydraulic actuation system 242, 342 of each arcing contact module 202a-202c, 302a-302c are opened by the control unit 206, 306. Pressurised dielectric liquid in the opening accumulator 236, 336 of each arcing contact module flows through the opening release valve 238, 338 and into the linear passageway 218, 318 through the opening inlet 222, 322 to provide hydraulic actuation that forces each moving contact 220, 320 towards an open position. The arcing contact modules 202a-202c, 302a-302c are actuated simultaneously, with minimal delay and, in the case of modules 302a-302c with two moving contacts 320, with rapidly increasing contact separation. As the moving contacts 220, 320 move towards the open position, they will come out of electrical contact with the surrounding first stationary contact 208, 308. The electrically conductive pathway between the ac terminals 230, 232 and 330, 332 of each arcing contact module 202a-202c, 302a-302c is broken at one location (single-break) or two locations (double-break), respectively. Initial arcing is established between each moving contact 220, 320 and the first stationary contact 208, 308. Arcing is rapidly established across the vents 212, 312 between adjacent first and second stationary contacts, 208, 210 and 308, 310. The pressurised dielectric liquid from the opening accumulator 236, 336 flows out of the linear passageway 218, 318 through the vents 213, 312. A liquid/gas mixture is therefore blasted through each annular vent 212, 312 and displaces the established arcs into the surrounding vent chambers 214, 314, rapidly removing heat and ionised material from the arcs in order to cause their extinction.

[0134] Each moving contact 220, 320 is brought to rest at the end of its opening stroke (i.e., in an open position) by the opposing hydraulic damper arrangement 228, 328.

[0135] Each arcing contact module 402a-402c that forms part of the ac circuit breaker 400 shown in Figure 6 has a virtually identical construction to the arcing contact modules 202a-202c described above.

[0136] With reference to Figure 11, each arcing contact module 402 includes a first stationary contact 410 and a second stationary contact 412 spaced apart from an end of the first stationary contact by an annular gap or vent 414 that defines a dielectric liquid outlet. The annular gap 414 may define an asymmetric outlet whose primary function is to allow any gas content within the gap to rise as a result of a combination of dielectric liquid flow and gravitational buoyancy effects and wherein the outlet communicates with the vent chamber 416 only at the uppermost part of the outlet 414. The outlet and vent can be constructed differently than the vent(s) in arcing modules for an open to protect arrangement because arcing is not expected under normal circumstances. For example, there is typically no need to construct the vent chamber 416 from insulation material or provide ablation protection for the outlet or vent.

[0137] An opening dielectric liquid inlet or port 418 is provided at the first stationary contact 410 and includes an opening 418' in fluid communication with the linear passageway 420. A closing dielectric liquid inlet or port 422 is provided at the second stationary contact 412 and includes an opening 422' in fluid communication with the linear passageway 420.

[0138] Hydraulic rebound damper arrangements 424, 426 are provided at the first stationary contact and at the secondary contact to bring the moving contact 428 to rest at the end of its closing and opening strokes as described in more detail herein. The moving contact 428 can move axially within the linear passageway 420 between the hydraulic rebound damper arrangements 424, 426.

[0139] Figure 12 is a schematic representation of the arcing contact module 402 shown in Figure 11 but includes the various external hydraulic circuits. The arcing contact module 402 is located between one of the ac lines 404a-404c and the ground (Gnd) 406 shown in Figure 6. The arcing contact module 402 includes an ac terminal 430 that is connected to one of the ac lines 404a-

404c that extends between the power supply PS and the load L, and an ac terminal 432 that is connected to ground (Gnd) 406.

[0140] A closing hydraulic actuation system includes a fast-acting hydraulic actuation means 434 that is fluidly connected to the closing inlet 422 and includes a closing accumulator 436, a closing release valve 438, and an opening drain valve 440. The closing inlet 422 is fluidly connected to the closing accumulator 436 through the closing release valve 438 and suitable liquid conduits, and is fluidly connected to an un-pressurised receiver of a drain system (not shown) through the respective opening drain valve 440 and suitable liquid conduits.

[0141] An opening hydraulic actuation system includes a hydraulic actuation means 442 that is fluidly connected to the opening inlet 418 and includes an opening accumulator 444, an opening release valve 446, and a closing drain valve 448. The opening inlet 418 is fluidly connected to the opening accumulator 444 through the opening release valve 446 and suitable liquid conduits (e.g., piping or tubing), and is fluidly connected to the un-pressurised receiver through the respective closing drain valve 448 and suitable liquid conduits. Each arcing contact module 402 can have its own drain system, or a common drain system can be shared between the arcing contact modules 402a-402c of the ac circuit breaker 400.

[0142] The vent chamber 416 is fluidly connected to a pressurised receiver of a vent system (not shown) by suitable liquid conduits that must be made of an electrically insulating material. Each arcing contact module 402 can have its own vent system, or a common vent system can be shared between the arcing contact modules 402a-402c of the ac circuit breaker 400.

[0143] The moving contact 428 is initially in an open position in electrical contact with the second stationary contact 412 but spaced apart from the first stationary contact 410 (i.e., in the position shown in Figure 11).

[0144] All arcing contact modules 402a-402c are controlled by the control unit 408 that receives a signal to close the ac circuit breaker 400 for protection purposes when a fault current is developed, or in response to an operator request. On receipt of a signal to close the ac circuit breaker 400, the closing release valve 438 in the closing hydraulic actuation system and the closing drain valve 448 in the opening hydraulic actuation system of each arcing contact module 402a-402c are opened by the control unit 408. Pressurised dielectric liquid in the closing accumulator 436 of each arcing contact module flows through the closing release valve 438 and into the linear passageway 420 through the closing inlet 422 to provide hydraulic actuation that forces the moving contact 428 towards a closed position. The arcing contact modules 402a-402c are actuated simultaneously, with minimal delay.

[0145] As the moving contact 428 moves towards the closed position, it will come into electrical contact with the surrounding first stationary contact 410. An electrically conductive pathway between the ac terminals 430, 432 of each arcing contact module 402a-402c is therefore established. This connects each ac line 404a-404c of the three-phase ac circuit to the ground connection 406.

[0146] The pressurised dielectric liquid that is displaced by the flow from the closing accumulator 436 and associated contact motion initially flows out of the linear passageway 420 through the vent 416. The dielectric liquid on the opening inlet-side of the moving contact 428 can also be displaced through the opening inlet 418 during closing of the ac circuit breaker 400 and this component of displaced flow corresponds with the contact motion once the moving contact 428 has entered the first stationary contact 410. Displaced dielectric liquid flows out of the linear passageway 420 through the opening inlet 418 to the un-pressurised receiver (not shown).

[0147] The moving contact 428 is brought to rest at the end of its closing stroke (i.e., in a closed position) by the opposing hydraulic damper arrangement 424.

[0148] The pressure of the closing hydraulic actuation system can be used to apply a force to the moving contact 428 to retain it in the closed position until the ac circuit breaker 400 needs to be opened (or reset). Prior to opening the ac circuit breaker 400 the closing release valve 438 must closed and the pressure in the closing accumulator 436 must be shown to be sufficient to rapidly reclose the ac circuit breaker 400.

[0149] On receipt of a signal to open the ac circuit breaker 400, the opening release valve 446 in the opening hydraulic actuation system and the opening drain valve 440 in the closing hydraulic actuation system are opened by the control unit 408. Pressurised dielectric liquid in the opening accumulator 444 flows through the opening release valve 446 and into the linear passageway 420 through the opening inlet 418 to provide hydraulic actuation that forces the moving contact 428 back towards the open position shown in Figure 11. The displaced dielectric liquid initially flows out of the closing inlet 422 to the un-pressurised receiver (not shown) but once the moving contact has separated from the first stationary contact 410, it may additionally flow through the vent chamber 416 and to the pressurised receiver (not shown).

[0150] The moving contact 428 is brought to rest at the end of its opening stroke by the opposing hydraulic damper arrangement 426. It will be readily appreciated that other, non-hydraulic means (e.g., mechanical means) can also be used for circuit breaker opening.

[0151] Single or multiple instances of double-break circuit breakers may benefit from having equal and opposite reaction forces in the axis of the linear passageway as a result of their substantially symmetrical and synchronous operation. The benefit manifests itself firstly, as a reduction in shock and vibration output, thereby allowing some economy to be made in supporting structures and, secondly, rendering the susceptibility of the two adjacent moving contacts to suffer simultaneous unintentional movement as a result of shock and vibration input. Similarly, the sliding arrangements are inherently immune to radial components of incoming shock and vibration.

Claims

1. An ac circuit breaker (200; 300; 400) comprising at least one arcing contact module (202a-202c; 302a-302c; 402a-402c), each arcing contact module comprising:

   a first dielectric fluid inlet (222; 322; 422);
   a first stationary contact (208; 308; 410);
   a second stationary contact (210; 310; 412), the first and second stationary contacts being spaced apart by a gap that defines a dielectric fluid outlet (212; 312; 414); and
   a moving contact (220; 320; 428), the moving contact being movable by the introduction of pressurised dielectric fluid through the first inlet (222; 322; 422) from:

   (a) a first position, to
   (b) a second position,

   to activate the ac circuit breaker (200; 300; 400).

2. An ac circuit breaker (200; 300) according to claim 1, wherein in the first position, the moving contact (220; 320) is in electrical contact with the first and second stationary contacts (208, 210; 308, 310) to provide an electrically conductive pathway between the first and second stationary contacts, and wherein in the second position, the moving contact (220; 320) is not in electrical contact with the first stationary contact (208, 308).

3. An ac circuit breaker (200; 300) according to claim 2, wherein arcing is initiated when the moving contact (220; 320) is moved towards the second position such that an arc is established across the gap between the first and second contacts (208, 210; 308, 310); and
   the circuit breaker (200; 300) is adapted such that the pressurised dielectric fluid that is introduced through the first inlet (222; 322) is blasted through the outlet (212; 312), thereby rapidly removing heat and ionised material from the arc in order to cause its extinction.

4. An ac circuit breaker (400) according to claim 1, wherein in the first position, the moving contact (428) is not in electrical contact with the first stationary contact (410), and wherein in the second position, the moving contact (428) is in electrical contact with the first and second stationary contacts (410, 412) to provide an electrically conductive pathway between the first and second stationary contacts (410, 412).

5. An ac circuit breaker (200; 300; 400) according to any preceding claim, wherein the first and second stationary contacts (208, 210; 308, 310; 410, 412) are substantially tubular and define a linear passageway (218; 318; 420) in fluid communication with the first inlet (222; 322; 422) and the outlet (212; 312; 414), wherein the moving contact (220; 320; 428) is positioned within the linear passageway.

6. An ac circuit breaker (200; 300; 400) according to any preceding claim, wherein each arcing contact module (202a-202c; 302a-302c; 402a-402c) further comprises a second dielectric fluid inlet (224; 324; 418), the moving contact (220; 320; 428) being movable by the introduction of pressurised dielectric fluid through the second inlet (224; 324; 418) from:

   (a) the second position, towards
   (b) the first position,
   to reset the ac circuit breaker (200; 300; 400).

7. An ac circuit breaker (200; 300; 400) according to claim 6, further comprising a resetting fluid actuation system (242; 342; 442) that is connected to the second inlet (224; 324; 418), the resetting fluid actuation system (242; 342; 442) comprising at least one resetting accumulator (244; 344; 444), at least one release valve (246; 346; 446), and at least one drain valve (248; 248; 448) connected to an un-pressurised receiver of a drain system.

8. An ac circuit breaker (200; 300; 400) according to any preceding claim, further comprising an activating fluid actuation system (234; 334; 434) that it is connected to the first inlet (222; 322; 422), the activating fluid actuation system (234; 334; 434) comprising at least one activating accumulator (236; 336; 436), at least one release valve (238; 338; 438), and at least one drain valve (240;340; 440) connected to an un-pressurised receiver of a drain system.

9. An ac circuit breaker (200; 300; 400) according to any preceding claim, further comprising a vent system including a pressurised receiver, and wherein the outlet (212; 312; 414) is connected to the pressurised receiver.

10. An ac circuit breaker (200; 300; 400) according to claim 9, further comprising a drain system including an un-pressurised receiver and a pump for pumping dielectric fluid in the un-pressurised receiver into the pressurised receiver of the vent system.

11. An ac circuit breaker (200; 300; 400) according to claim 9 or claim 10, further comprising an activating accumulator (236; 336; 436) and a resetting accumulator (244; 344; 444), and wherein the vent system includes out-gassing means for out-gassing the

vent system, and at least one pump for pumping the out-gassed dielectric fluid to pressurise the activating and resetting accumulators (236, 244; 336, 344; 436, 444).

12. An ac circuit breaker (200; 300; 400) according to any preceding claim, comprising a plurality of arcing contact modules (202a-202c; 302a-302c; 402a-402c) arranged in parallel, with each arcing contact module being provided:

in a respective phase of an ac circuit (204a-204c; 304a-304c), or
between a pair of phases of an ac circuit, or
between a respective phase of an ac circuit (402a-402c) and a ground connection (406), or
between a respective phase of an ac circuit and an interconnection
point,
and being adapted to be activated in a synchronous manner.

13. A method of operating an ac circuit breaker (200; 300; 400) comprising at least one arcing contact module (202a-202c; 302a-302c; 402a-402c), each arcing contact module comprising:

a first dielectric fluid inlet (222; 322; 422);
a first stationary contact (208; 308; 410);
a second stationary contact (210; 310; 412), the first and second stationary contacts being spaced apart by a gap that defines a dielectric fluid outlet (212; 312; 414); and
a moving contact (220; 320; 428);
the method comprising the steps of:

on receipt of a signal to activate the ac circuit breaker (200; 300; 400), introducing pressurised dielectric fluid through the first inlet (222; 322; 422) to move the moving contact (220; 320; 428) from:

(a) a first position, to
(b) a second position.

14. A method according to claim 13, wherein each arcing contact module (202a-202c; 302a-302c; 402a-402c) further comprises a second dielectric fluid inlet (224; 324; 418);
the method comprising the steps of:

on receipt of a signal to reset the ac circuit breaker (200; 300; 400), introducing pressurised dielectric fluid through the second inlet (224; 324; 418) to move the moving contact (220; 320; 428) from:

(a) the second position, towards
(b) the first position.

15. A method according to claim 14, wherein dielectric fluid is circulated through the ac circuit breaker (200; 300; 400) after circuit breaker activation for a predetermined period or until the ac circuit breaker (200; 300; 400) is reset.

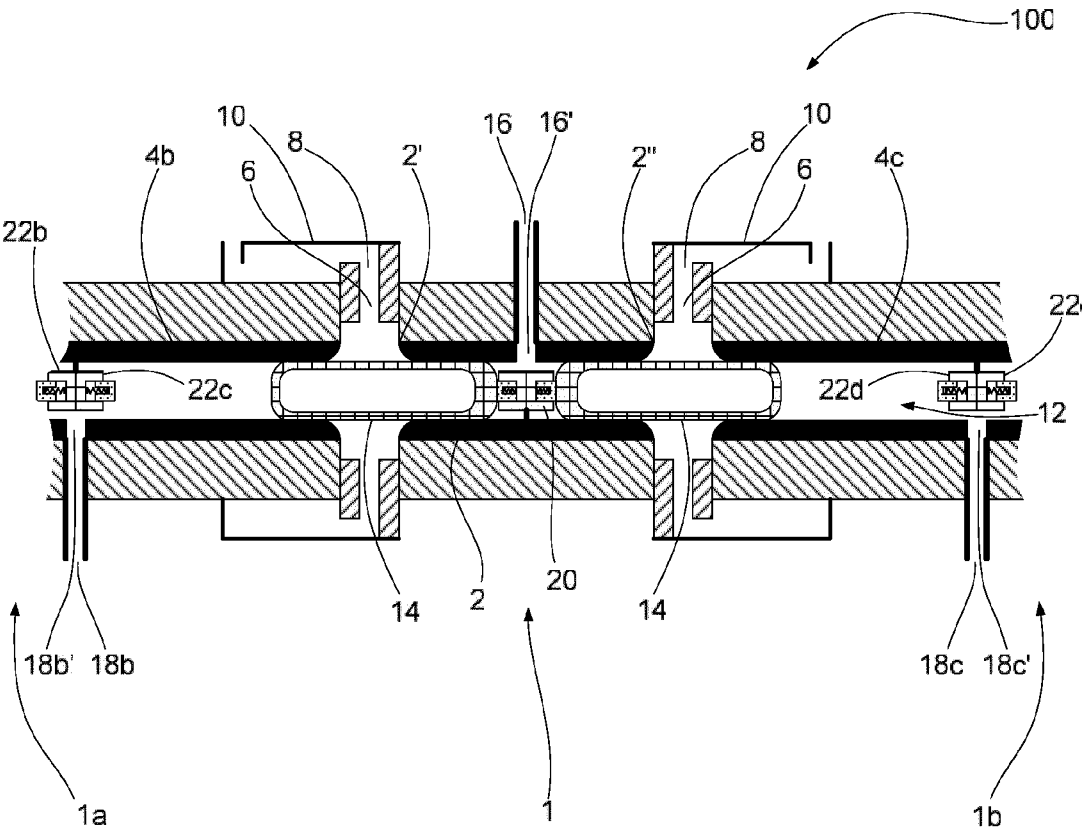
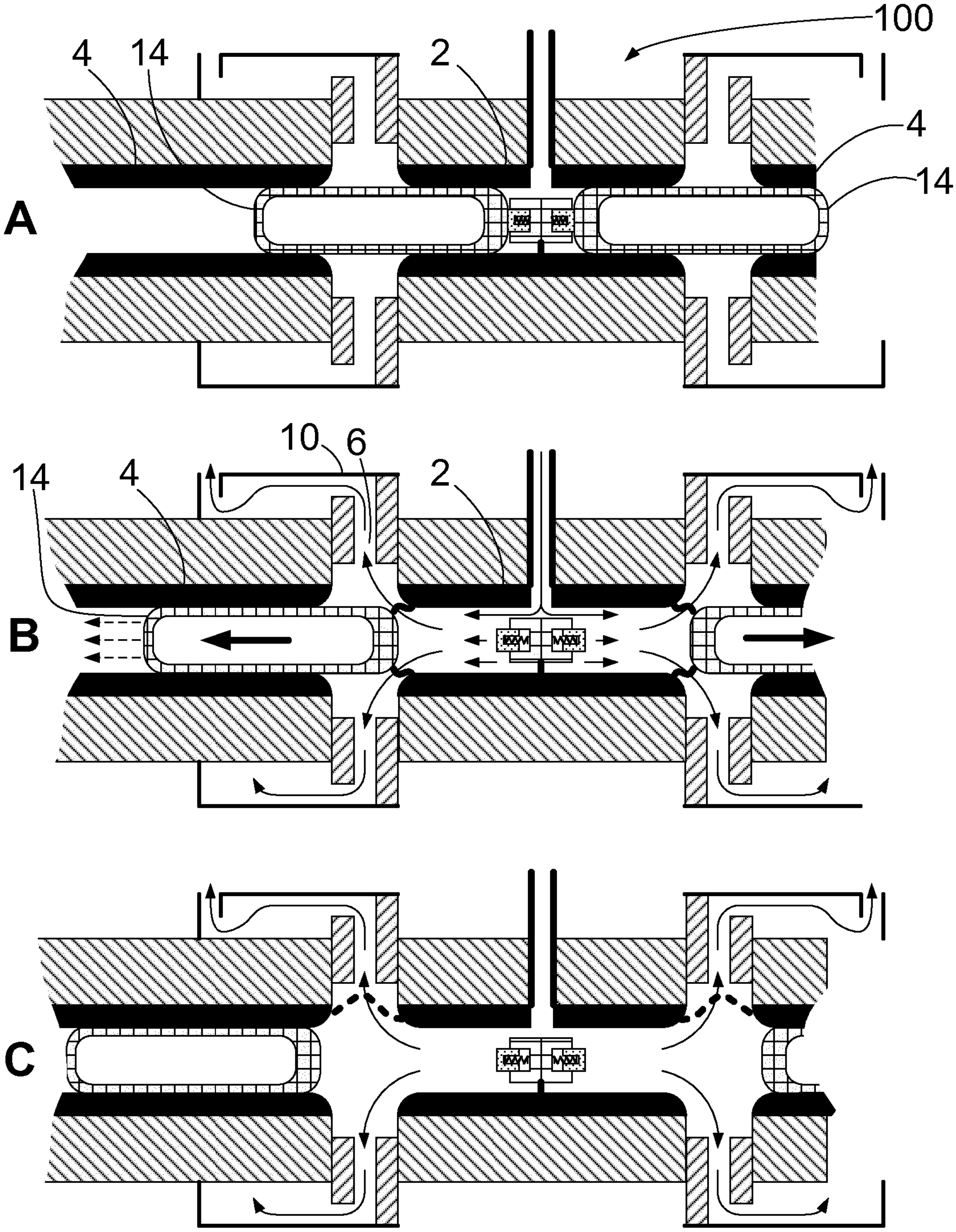

100
10
8
6
4b
2'
16
16'
2"
8
10
6
4c
22b
22e
22c
22d
12
14
2
20
14
18b'
18b
18c
18c'
1a
1
1b

Figure 1



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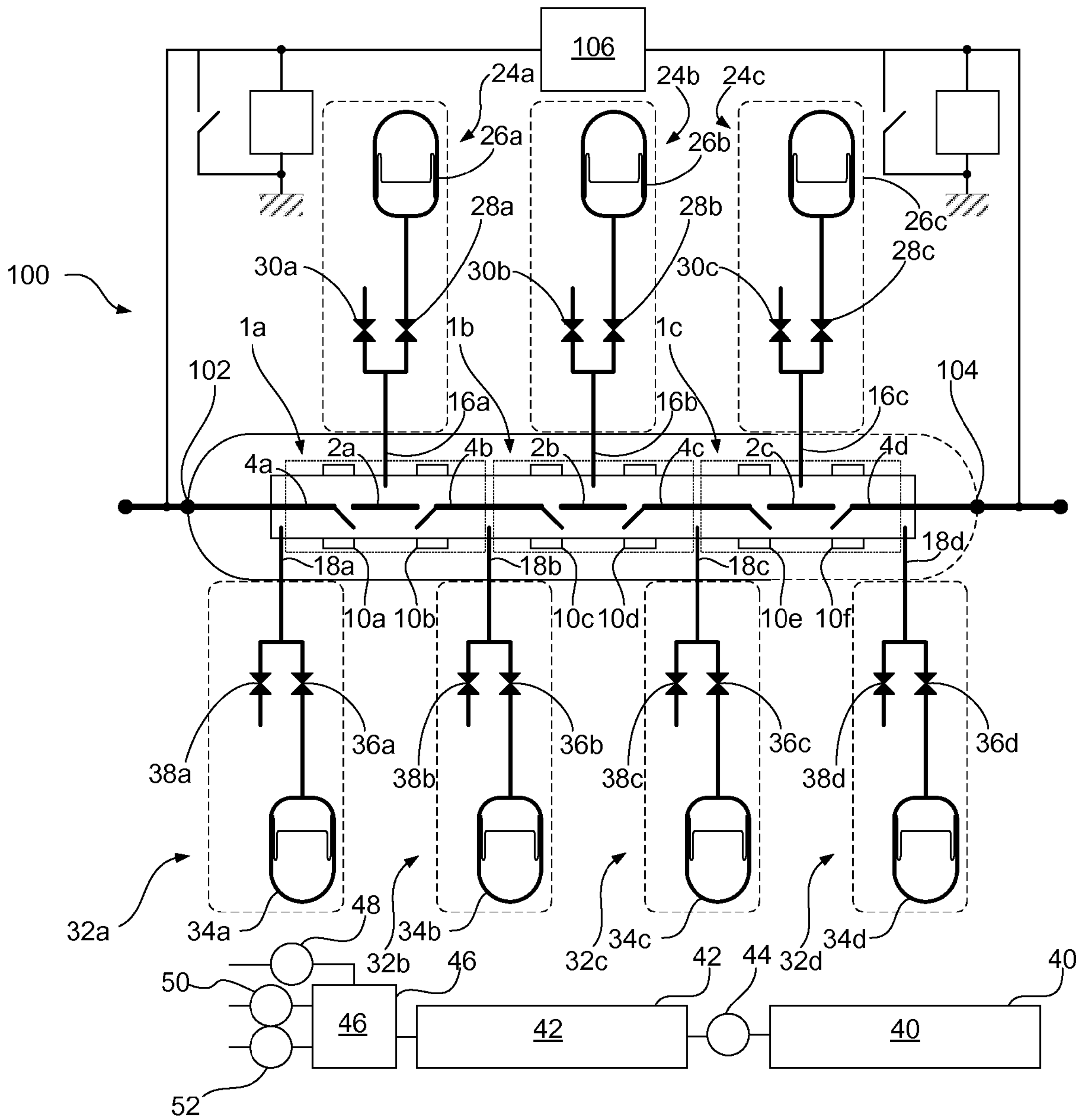
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28c
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1a
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102
104
16a
16b
16c
2a
4b
2b
4c
2c
4d
4a
18a
18b
18c
18d
10a
10b
10c
10d
10e
10f
36a
36b
36c
36d
38a
38b
38c
38d
32a
34a
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34b
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34c
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42
44
32d
34d
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50
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42
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52

Figure 3A

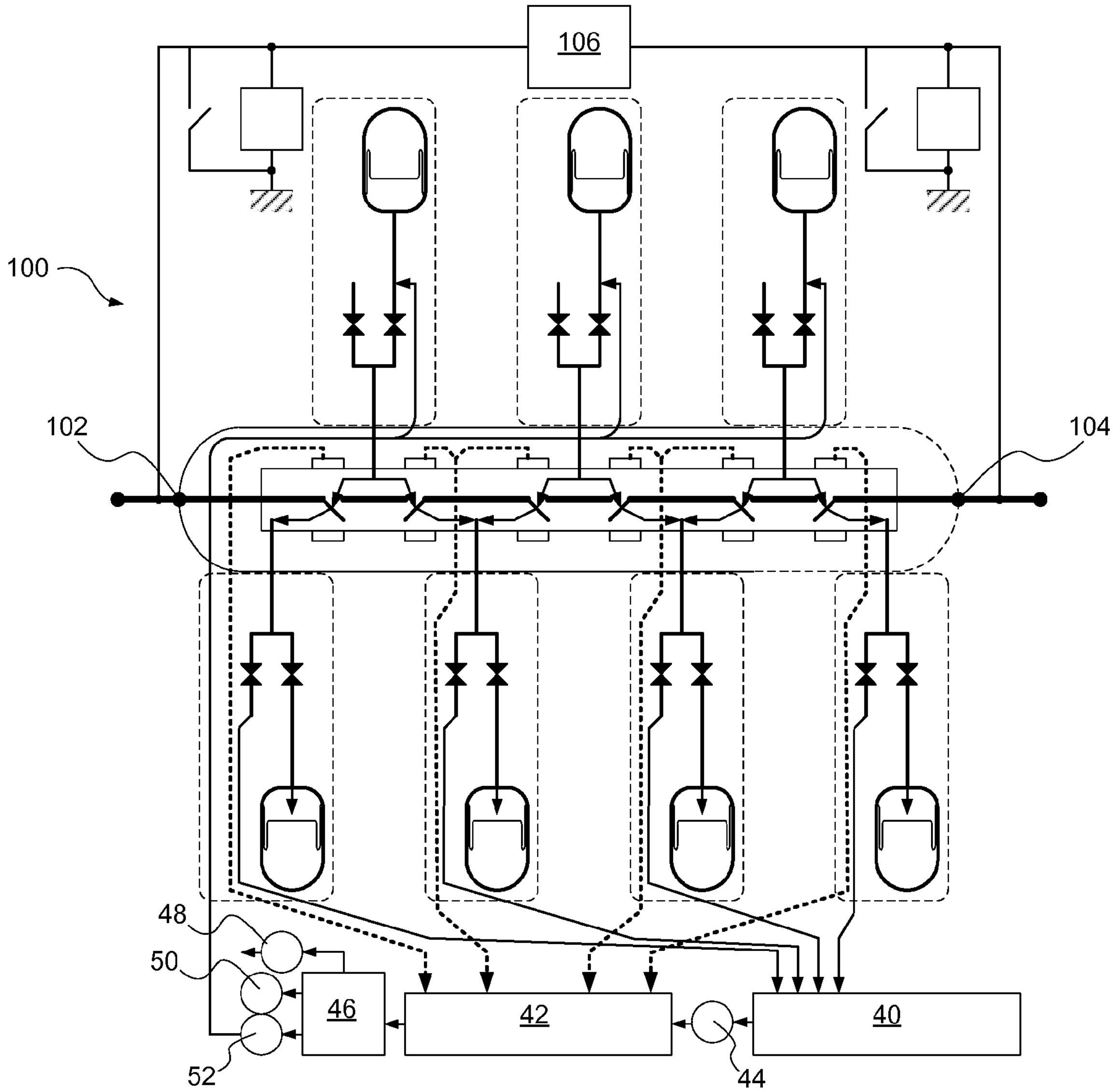


Figure 3B

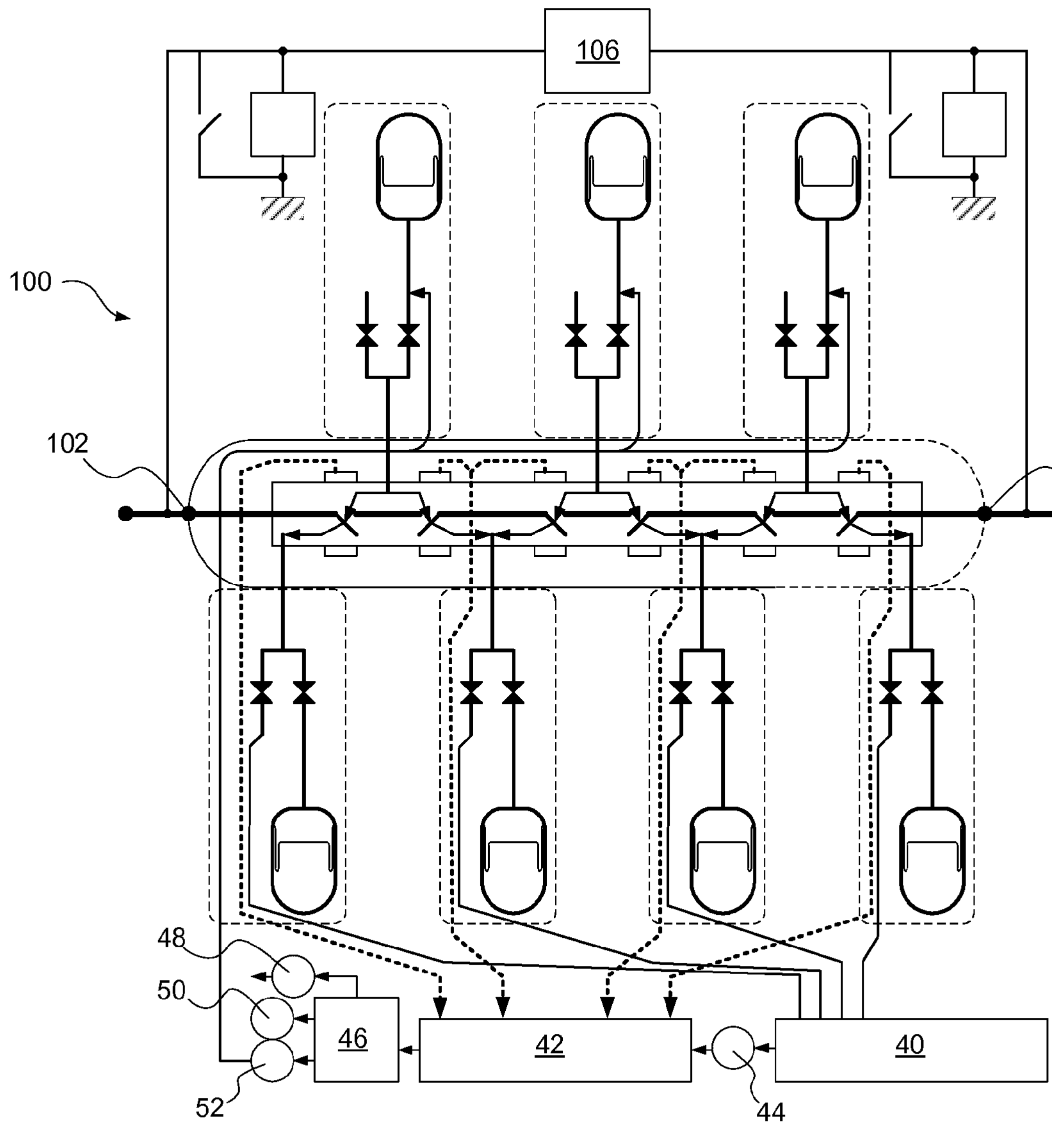


Figure 3C

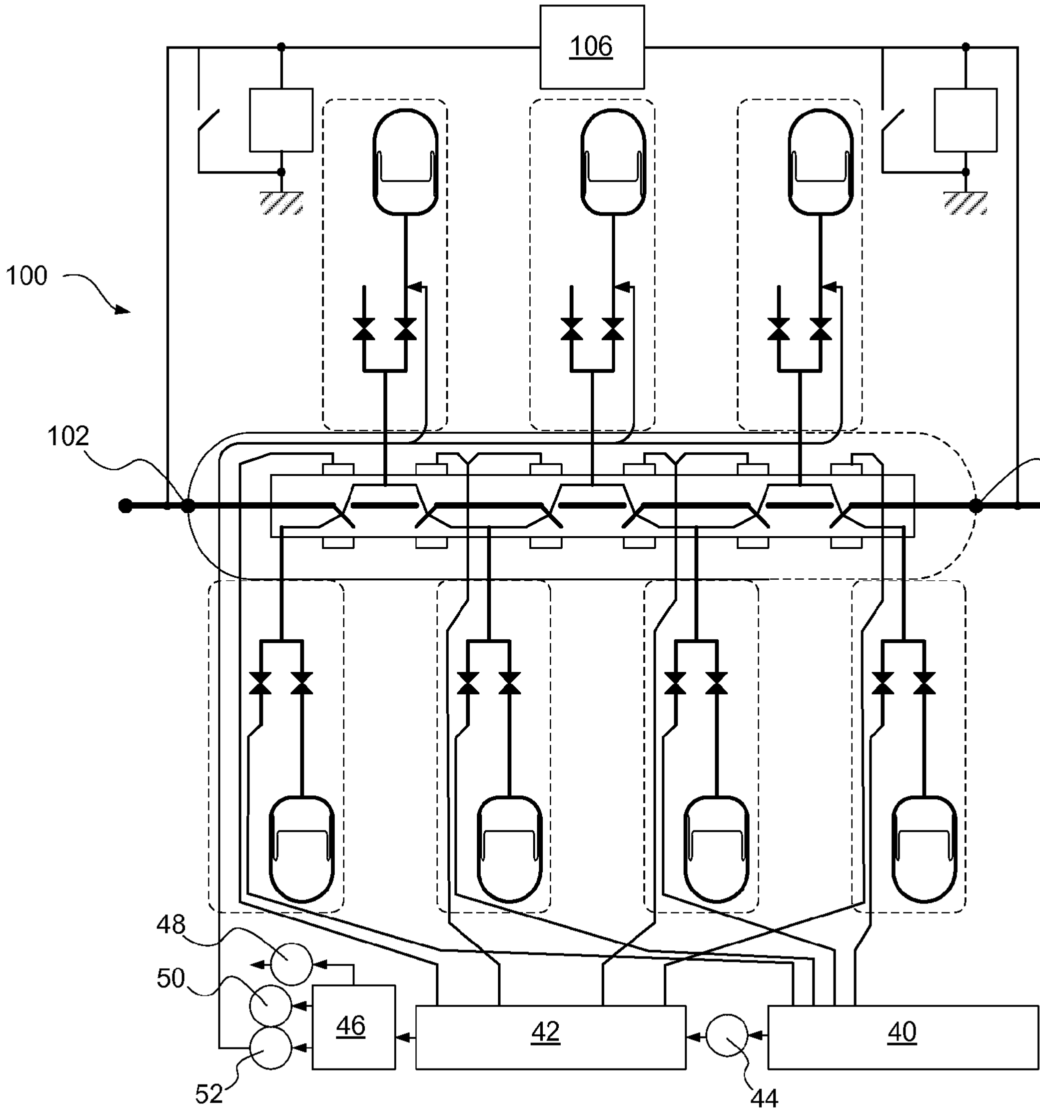


Figure 3D

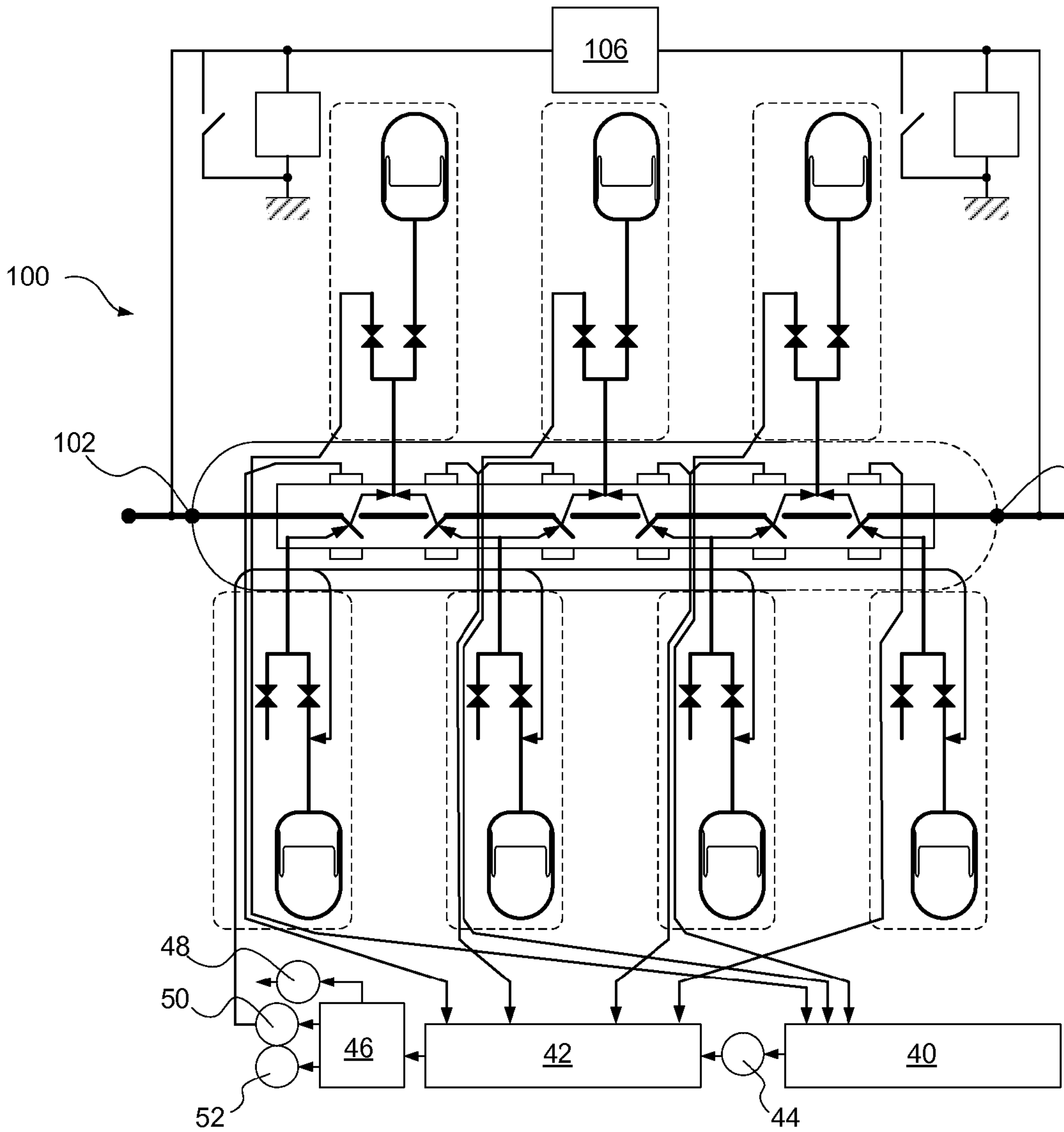
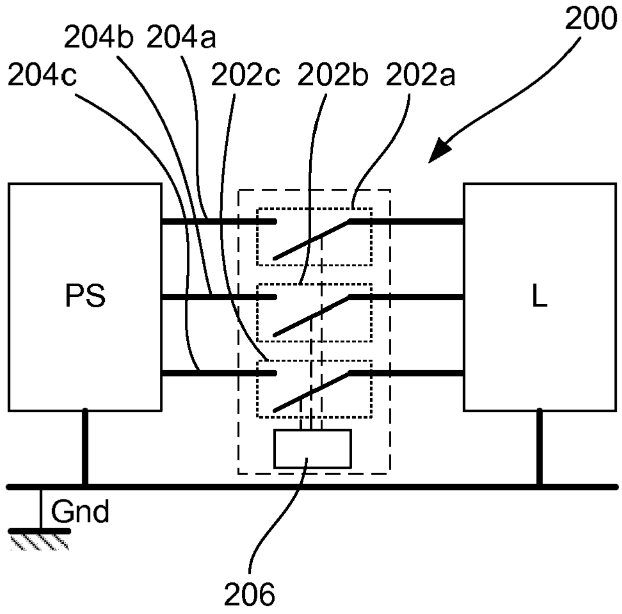


Figure 3E



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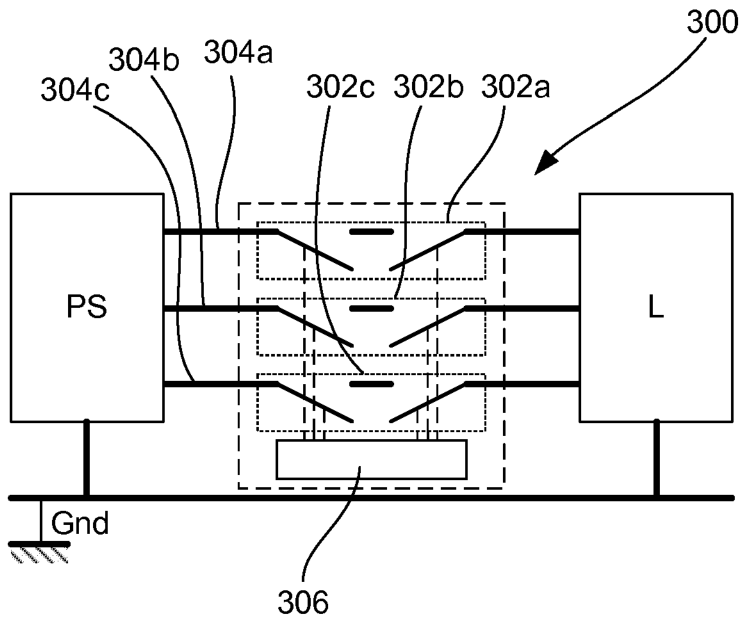

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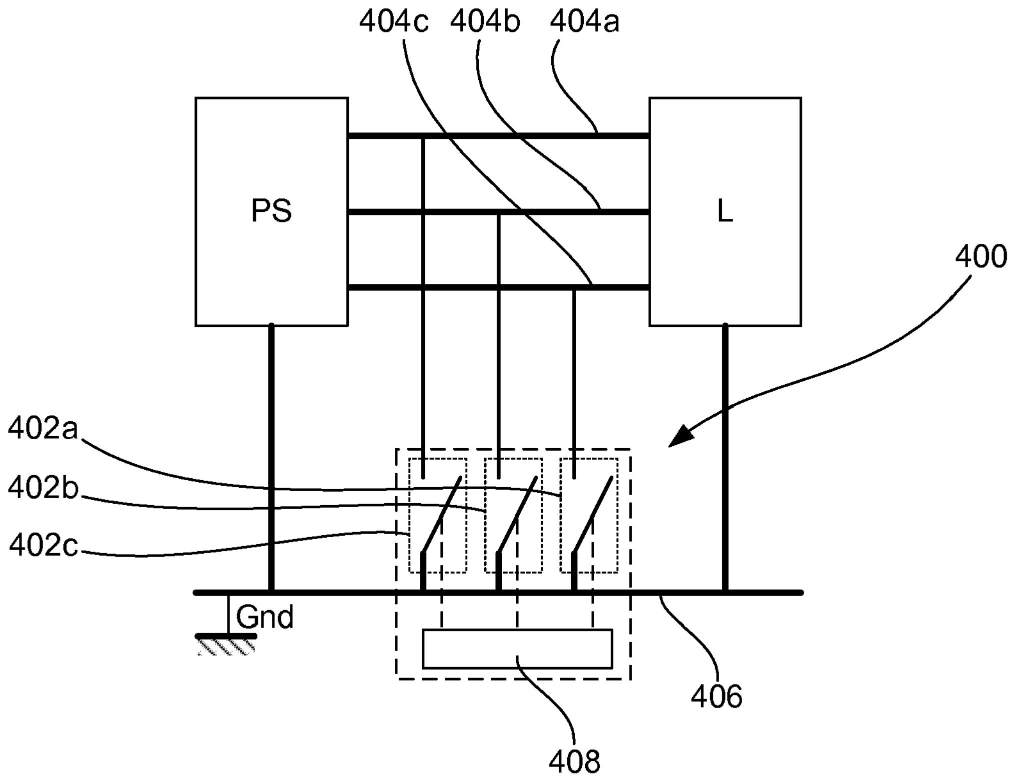
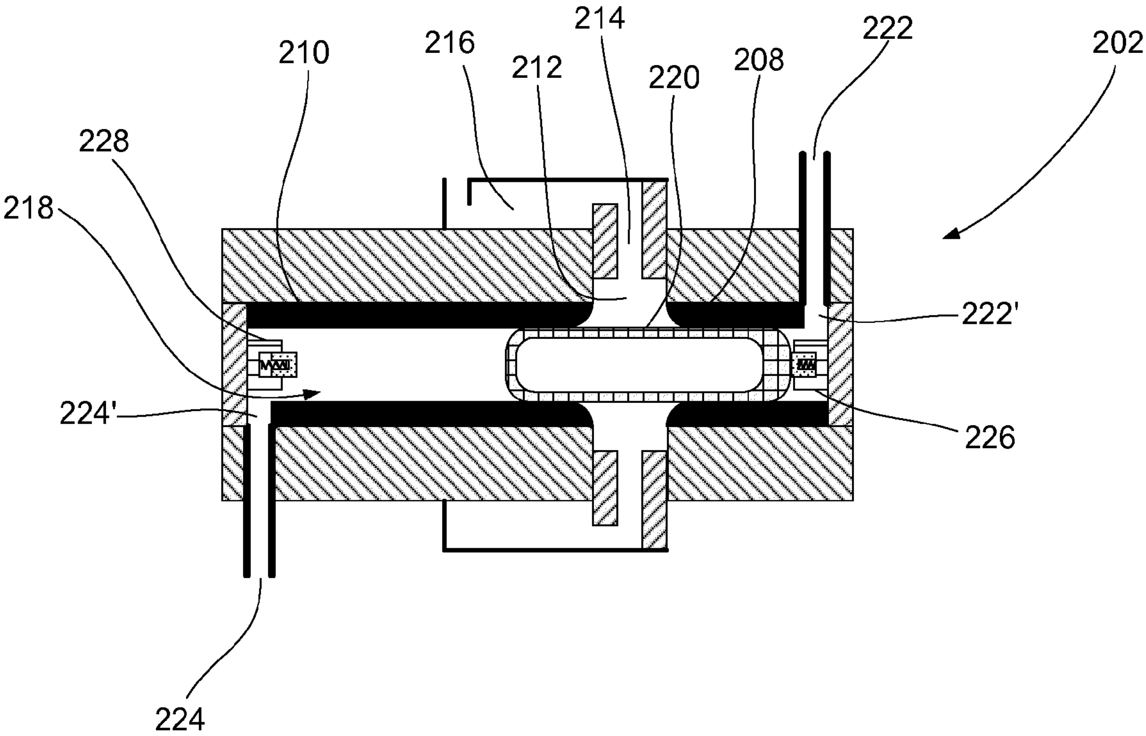


Figure 6



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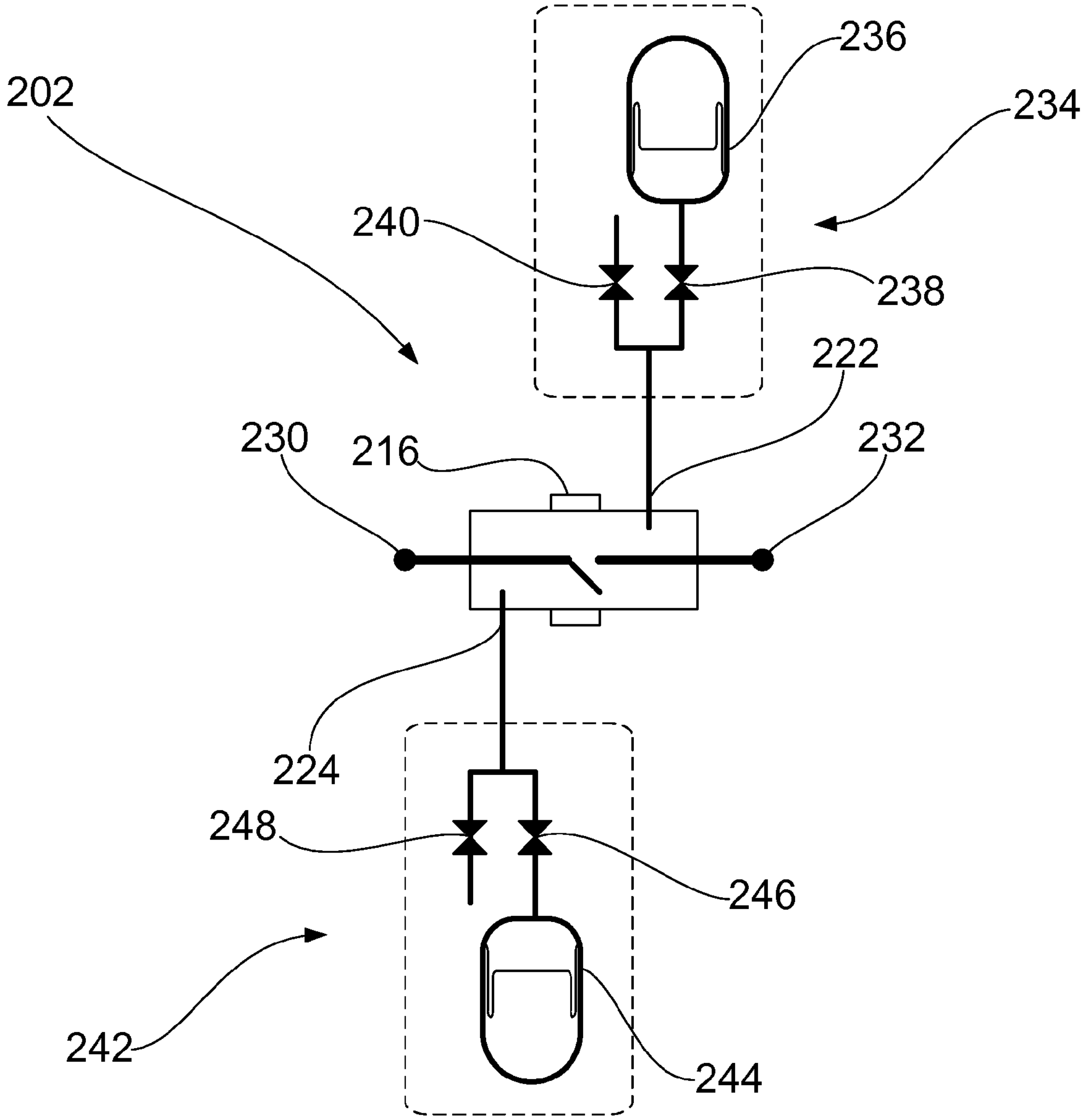
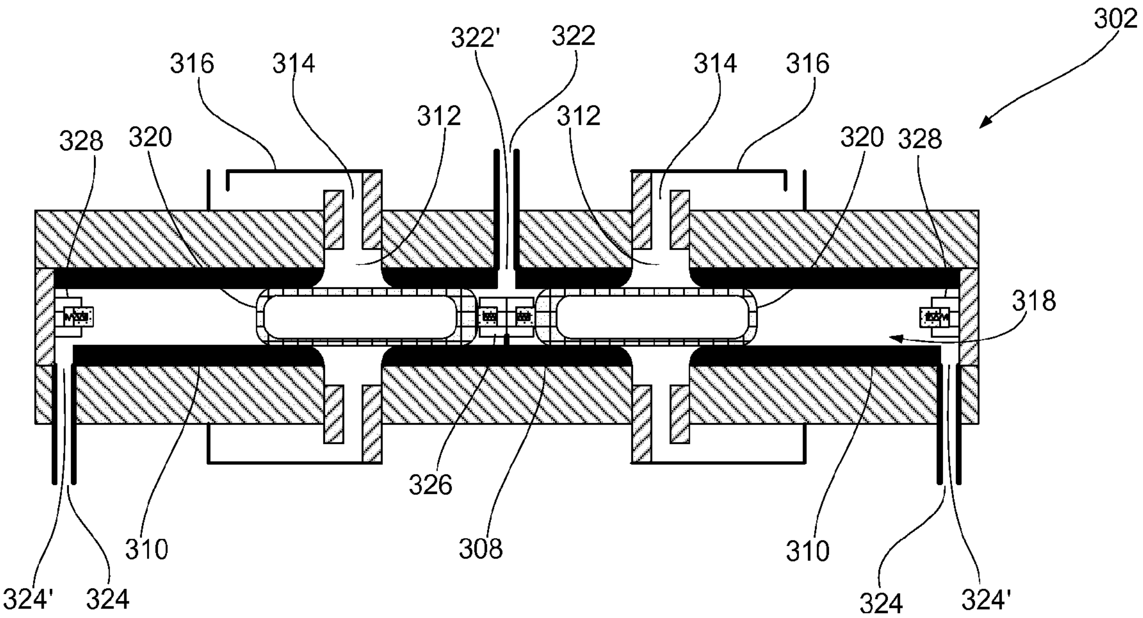


Figure 8


302
316
314
322'
322
314
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312
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328
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320
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318
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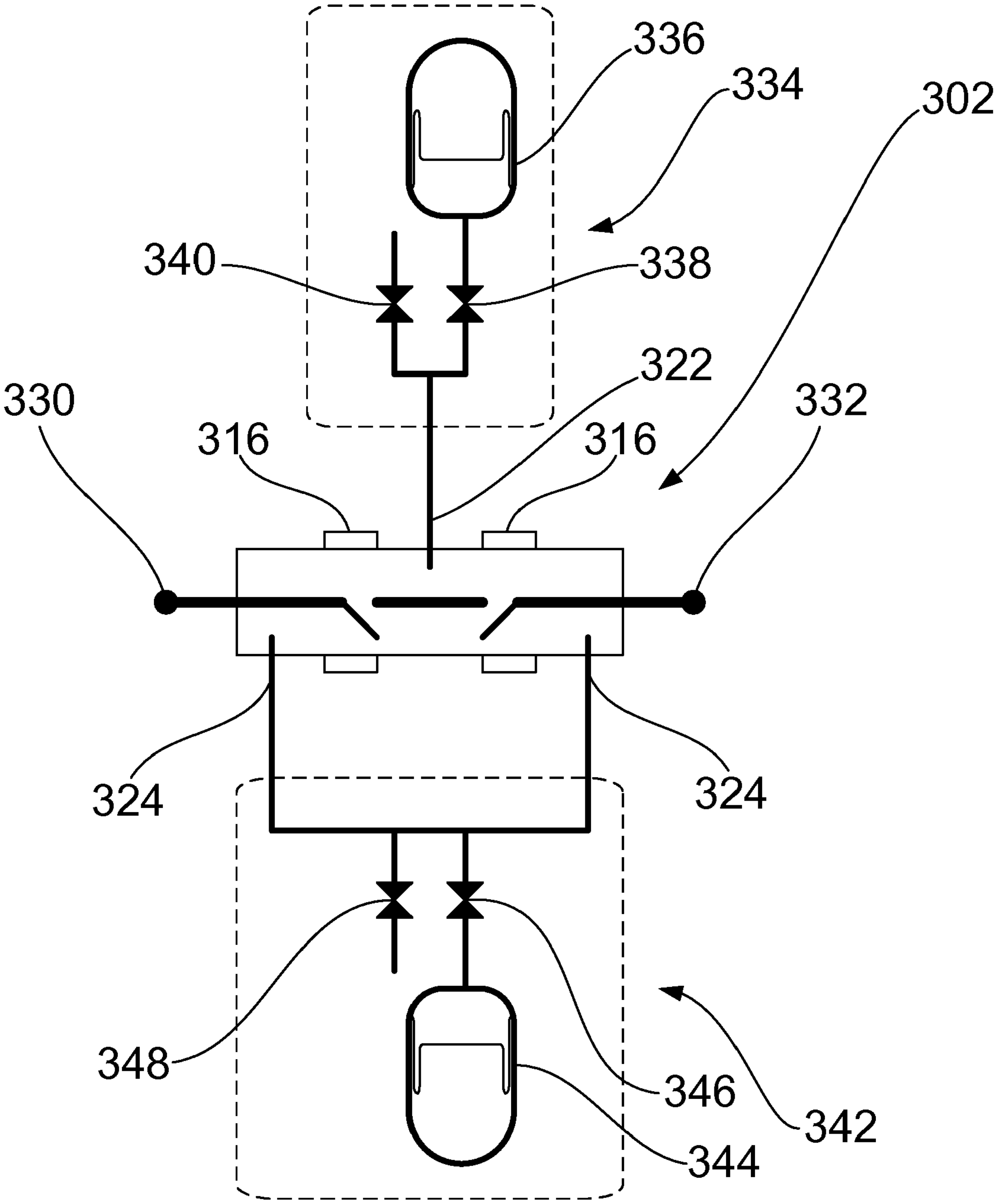
308
310
324'
324
324
324'

Figure 9



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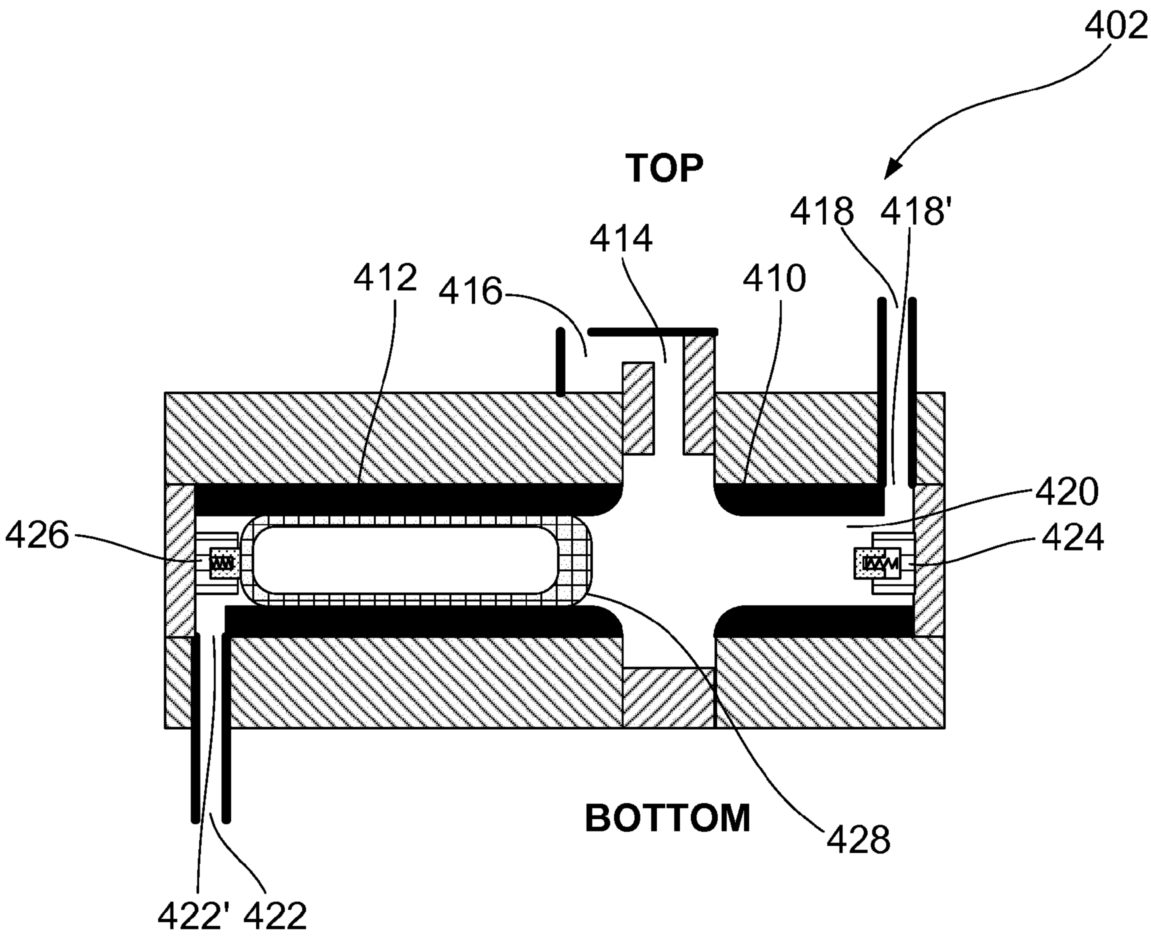

Figure 11

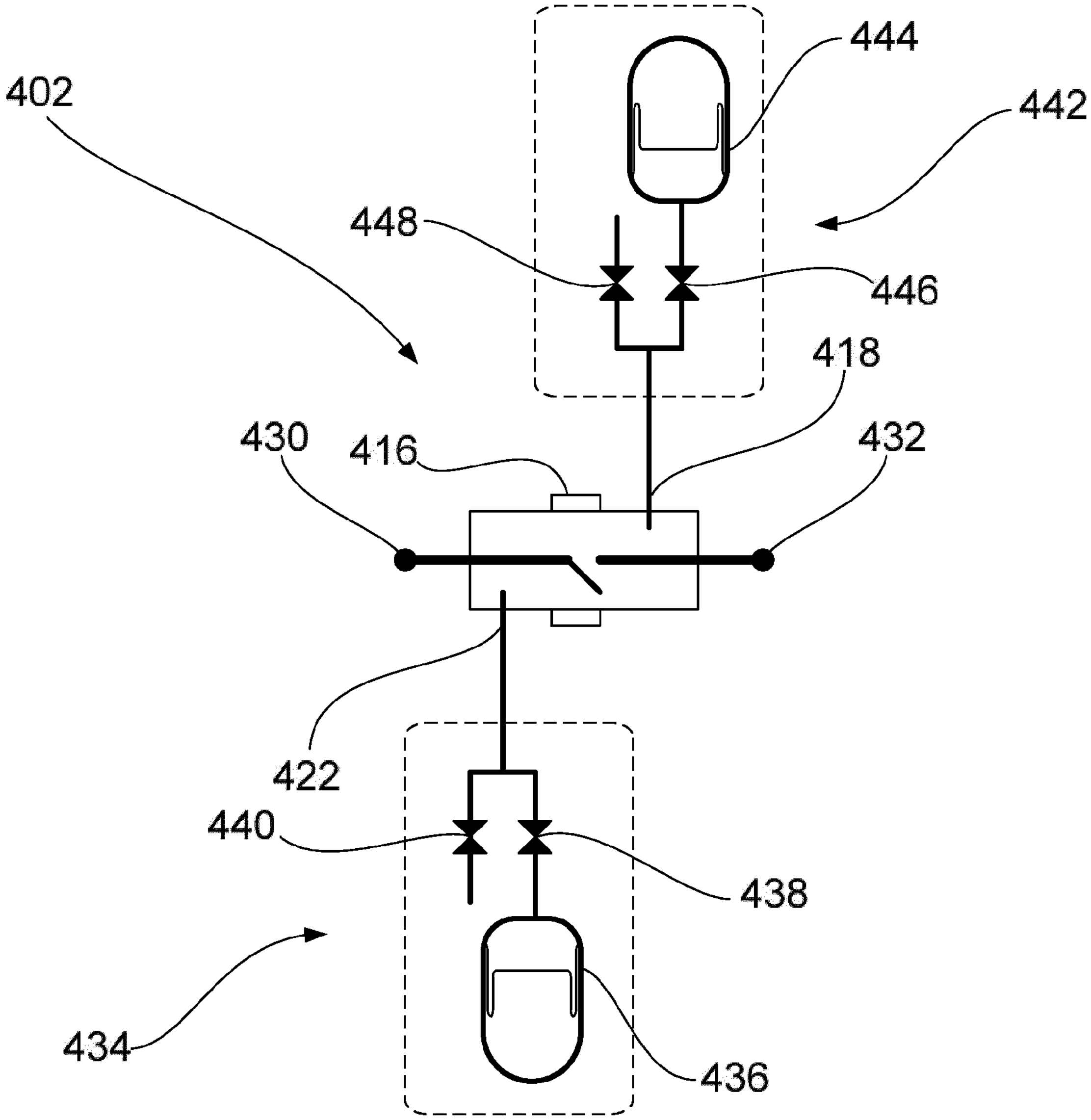

Figure 12

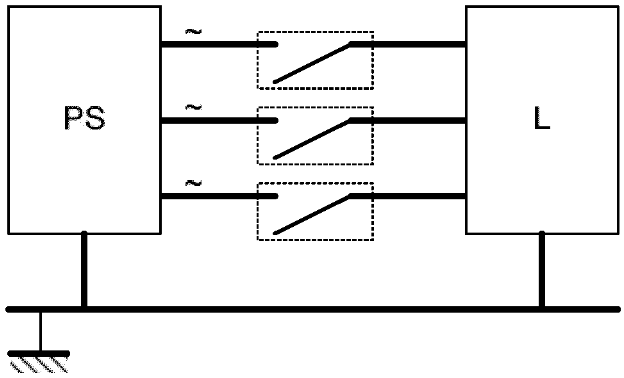

Figure 13A

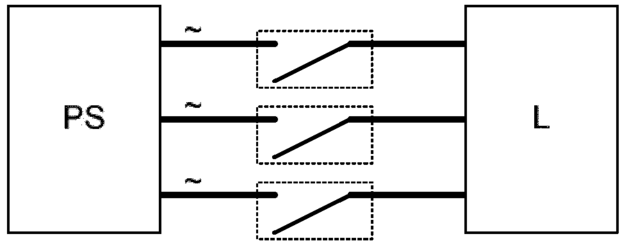

Figure 13B

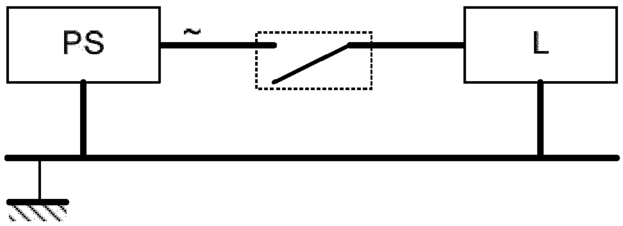

Figure 13C

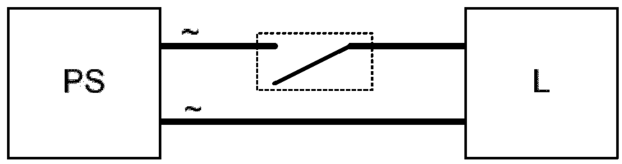

Figure 13D

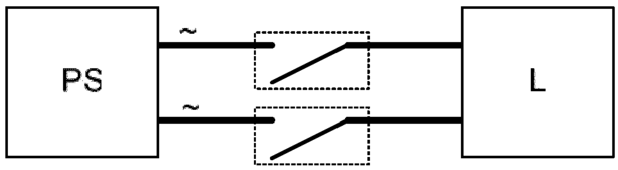

Figure 13E

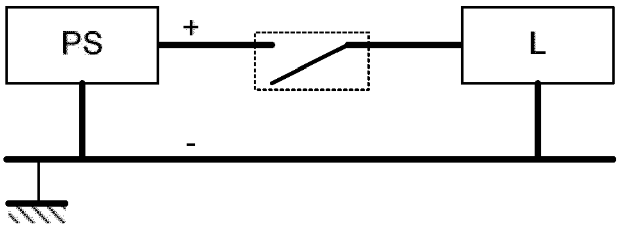

Figure 13F

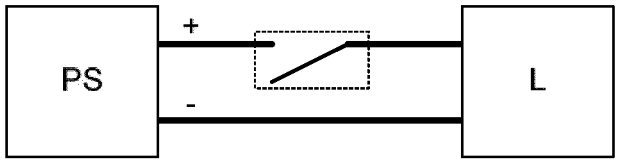

Figure 13G

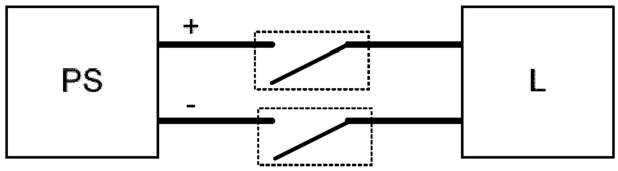

Figure 13H

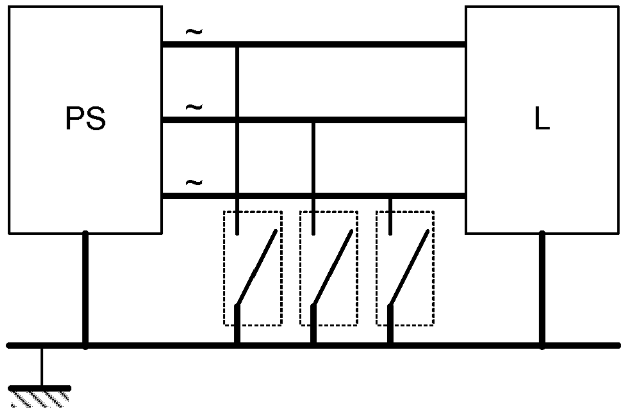

Figure 13I

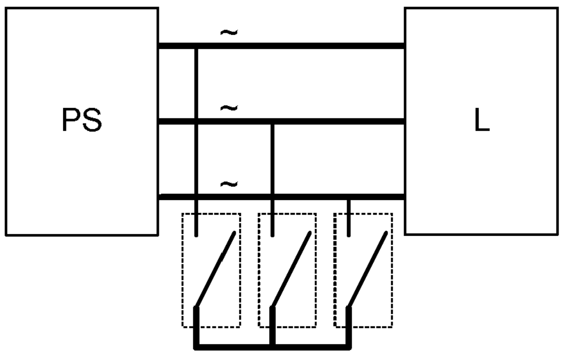

Figure 13J

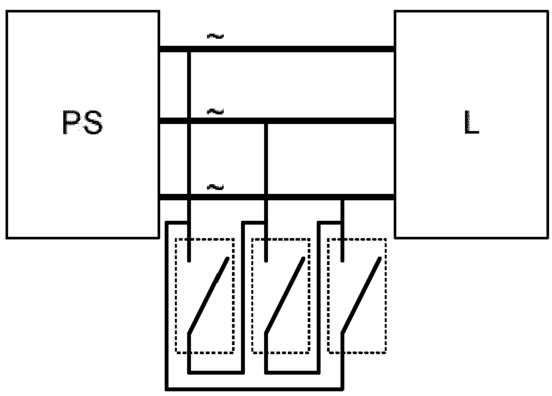

Figure 13K

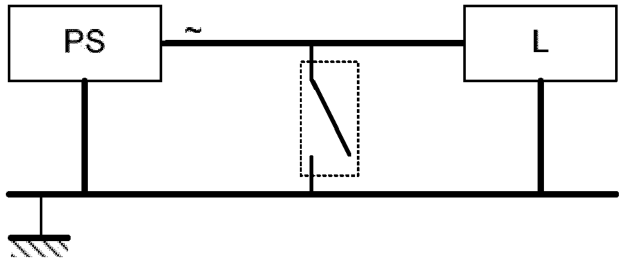

Figure 13L

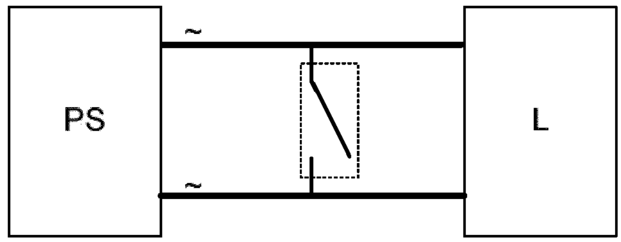

Figure 13M

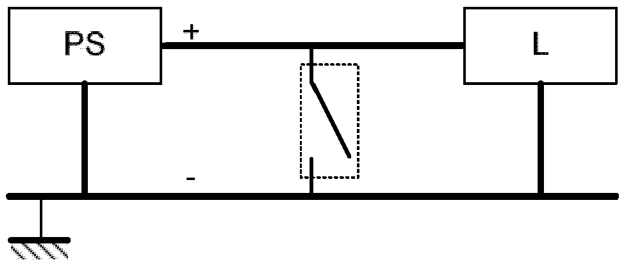

Figure 13N

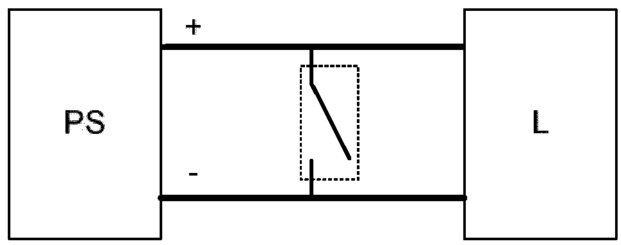

Figure 13O

Figure 13P

Figure 13Q

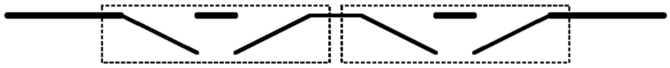

Figure 13R

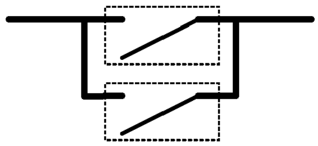

Figure 13S

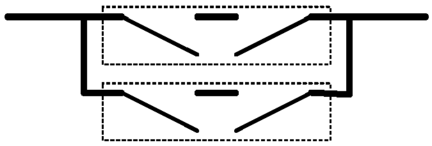

Figure 13T

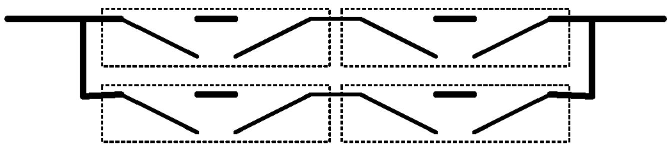

Figure 13U

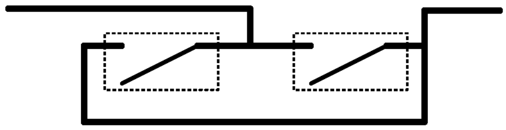

Figure 13V

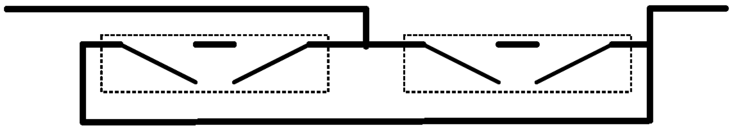

Figure 13W

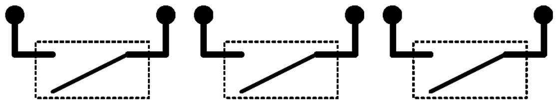

Figure 13X

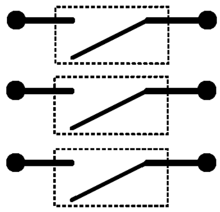

Figure 13Y

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EUROPEAN SEARCH REPORT

Application Number
EP 14 18 0619

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	WO 2013/167319 A1 (SIEMENS AG [DE]) 14 November 2013 (2013-11-14) * abstract; figures 1,4 * -----	1,4,6, 12-15	INV. H01H33/30 ADD. H01H1/38
X	US 2 886 672 A (HAAKON FORWALD) 12 May 1959 (1959-05-12) * the whole document * -----	1-3,5,7, 8,13,14	
X	FR 1 297 821 A (MERLIN GERIN) 6 July 1962 (1962-07-06) * the whole document * -----	1,13	
X	WO 2009/076975 A1 (ABB TECHNOLOGY AG [CH]; GENTSCH DIETMAR [DE]) 25 June 2009 (2009-06-25) * abstract; figure 1 * -----	1,13	
X	US 3 555 279 A (MANZ HANS ET AL) 12 January 1971 (1971-01-12) * abstract; figures 4a,4b * -----	1,9,11, 13	
X	US 3 553 406 A (BOERSMA RINTJE) 5 January 1971 (1971-01-05) * claim 1; figure 2 * -----	1,13	TECHNICAL FIELDS SEARCHED (IPC) H01H

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
Munich	15 December 2014	Simonini, Stefano

CATEGORY OF CITED DOCUMENTS

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15-12-2014

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