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(54) **Hybrid switch**

(57) Hybrid switch including a mechanical switch (2), at least a first static switch (9) placed on a first branch (R1) parallel with the contacts (2a, 2b) of the mechanical switch (2) and a backup charge (15), in particular a capacitor, placed on a second branch (R2) parallel with the contacts (2a, 2b) of the mechanical switch (2) and cou-

plable with/decouplable from the mechanical switch (2) by means of a second static switch (16). An electronic control unit (35) executes at least one control cycle of the first static switch (9) and of the second static switch (16) to extinguish the arc that forms between the contacts (2a, 2b) subsequent to under load opening of the mechanical switch (2).

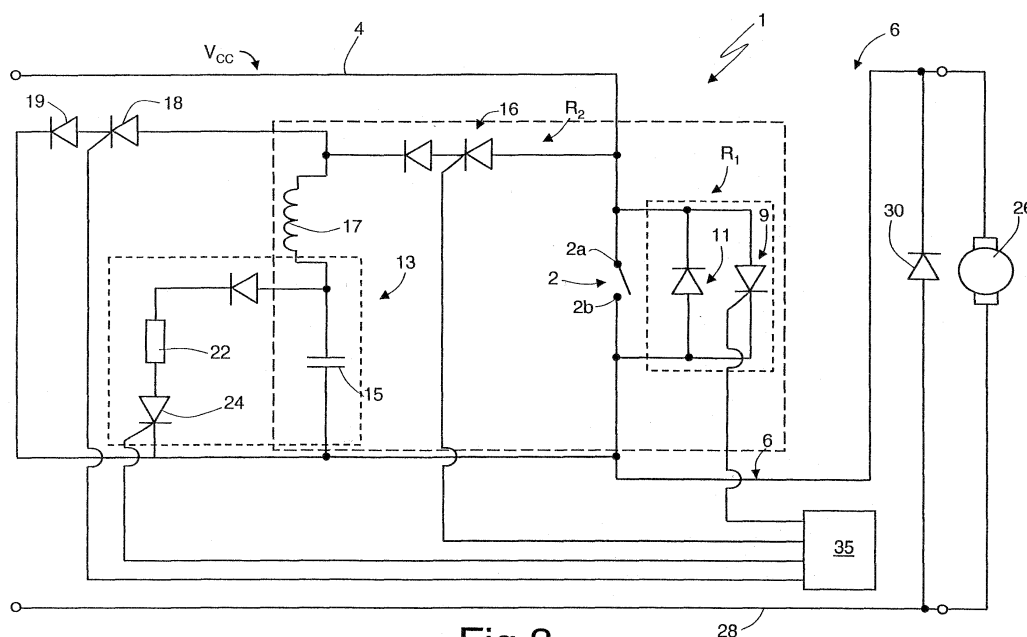


Fig.3

Description

[0001] The present invention relates to a hybrid switch.

[0002] As it is known, the use of conventional electro-mechanical switches for direct current applications is associated with a series of problems consisting essentially of the high switching times and of the presence of an electric arc produced between the contacts during opening under load; in particular, this latter phenomenon causes rapid deterioration in the contacts which must be dealt with through costly periodic maintenance, with replacement of parts, to safeguard the performance of the switch in time.

[0003] Static switches, produced using semiconductor components, have extremely short switching times and do not produce electric arcs; however, these switches are associated with high conduction losses.

[0004] By integrating the above technologies with each other it is possible to produce hybrid structures that enhance the advantages of both, reducing the respective drawbacks.

[0005] Hybrid structures known in the literature are essentially of two types, namely **ZVS** (Zero Voltage Switching) and **ZCS** (Zero Current Switching).

[0006] These structures are suitable to reduce the power transferred to the electric arc during current interruption, thereby reducing the opening times and the size of the electric arc.

[0007] According to ZVS technology, a hybrid switch (Figure 1) is produced including a mechanical switch **MS** coupled with a static switch **TS** (constituted in the example in Figure 1 consists in two IGBTs T1, T2, placed in series with each other) placed in parallel with the contacts of the mechanical switch **MS**. The structure of the static switch is completed by the capacities of clamps **C1**, **C2** and by the resistors **R1**, **R2** placed in parallel with the respective IGBTs T1, T2. A switch of the type illustrated above is described in the patent application EP 1 168 397 entitled "Static Power Switch Device".

[0008] The opening steps of a ZVS hybrid switch include:

- opening of the mechanical switch **MS**;
- simultaneous to opening control, closing of the static switch **TS** is executed.

[0009] In this way, when actual separation of the contacts of the mechanical switch **MS** starts, an arc is formed therebetween and a difference in potential occurs which is greater than the drop in potential at the ends of the static switch **TS** and which is sufficient to transfer the current from the mechanical switch **MS** to the static switch **TS**.

[0010] When the arc is extinguished and the contacts of the mechanical switch **MS** are sufficiently far apart to prevent reignition of the arc the opening of the static switch **TS** is controlled.

[0011] In the closing step the operations are executed

in the reverse order. The static switch **TS** is closed first; the mechanical switch **MS** is closed subsequently, with a voltage of a few volts; in this case, if the static switch **TS** were to be closed on a short circuit, it would be re-opened immediately, within reaction times of a few millionths of second, and the mechanical switch **MS** would not be made to close at all, as explained in greater detail below.

[0012] The **ZVS** technology illustrated above requires static switches capable of withstanding the entire current that is interrupted, which in the case of a fault can be significantly higher than the rated current of the switch. These static switches must be mounted strictly coupled with the electromechanical contacts to minimize parasitic reactances between mechanical switch and static switch, which determine the value and duration of the arc voltage.

[0013] For the reasons explained above, **ZVS** hybrid switches have large dimensions as static switches must be dimensioned as a function of the maximum current to be interrupted, the value of which depends on the maximum current admissible in the switch, on the separation time of the contacts (fractions of millisecond at best) and on the derivative of the fault current. As a result, **ZVS** hybrid switches are difficult to produce for high powers.

[0014] According to **ZCS** technology a hybrid switch is produced (Figure 2) including a mechanical switch **MS** coupled with an inductive-capacitive circuit **LC** implemented on a branch parallel with the contacts of the mechanical switch **MS**. This parallel branch is connectable to/disconnectable from the contacts by means of a static switch **TH**, for example a thyristor. Generally, a bypass diode **D** is placed between the contacts of the mechanical switch **MS**.

[0015] Opening of a **ZCS** hybrid switch includes the following steps:

- To control the opening of the mechanical switch **MS**;
- optional stand-by and closing of the static switch **TH**.

[0016] This results in a sinusoidal pulse of current passing into the loop that includes the inductive-capacitive circuit, the static switch **TH**, the mechanical switch **MS** (or a diode **D** placed in parallel with the mechanical switch **MS**).

[0017] For successful opening to take place it is necessary that:

- the direction of the pulse current is opposite in the mechanical switch **MS** is in an opposite direction to the direction of the current to be opened;
- the amplitude of the pulse current is sufficient to cancel the current in the mechanical switch **MS**; any excess current flows into the diode **D**, preventing re-strike. Thus, with reversal of the current the arc on the mechanical switch **MS** is extinguished. During passage of the current in the diode **D**, there is practically no voltage at the ends of the diode **D** and of the mechanical switch **MS**;

- the duration of the pulse and the opening speed of the mechanical switch MS must be coordinated so that when, following depletion of the pulse, the current in the diode is cancelled and the mechanical switch Ms is capable of withstanding the voltage that is re-applied.

[0018] A ZCS hybrid switch requires minimization of the inductance only of the loop including the mechanical switch MS and the diode D.

[0019] Therefore, the ZCS switch is preferable to the ZVS switch, which requires minimization of the inductances of the entire loop including the mechanical switch MS and the static switch TS. The ZCS layout therefore allows the mechanical switch MS and the diode D to be placed separately from the rest of the electronic components.

[0020] Consequently, the layout of the ZCS hybrid switch allows greater freedom with respect to ZVS technology.

[0021] The ZCS hybrid switch also has the important characteristic of not requiring (as is instead the case for the ZVS layout) semiconductors capable of carrying high currents. It can be produced with thyristors, i.e. with simple, reliable and relatively inexpensive semiconductor components.

[0022] Nonetheless, the ZCS switch has some drawbacks.

[0023] The capacitor C of the resonant circuit present in the ZCS layout must store considerable energy. Therefore, it is bulky and costly, and must be kept suitably charged at all times during operation to ensure an adequate current pulse. Moreover, according to the ZCS layout, the pulse current cannot be regulated and therefore the full pulse current is delivered even in the case of opening of currents considerably lower than the rated current carried by the mechanical switch.

[0024] Another drawback of the ZCS layout is that the closing operation (unlike the ZVS type) cannot be executed by first closing the static switch TS and only subsequently the mechanical switch MS; therefore the electric arcs that develop during closing under load (also caused by bouncing of the contacts) cannot be eliminated and, above all in the case of short circuit closing, the times of the re-opening operation are conditional upon the re-opening times of the mechanical contacts; while the ZVS switch does not have these drawbacks.

[0025] The object of the present invention is to produce a hybrid switch that overcomes the drawbacks of prior art hybrid switches.

[0026] The preceding object is achieved by the present invention as it relates to a hybrid switch characterized in that it includes: a mechanical switch; at least one first static switch placed on a first branch (R1) parallel with the contacts of the mechanical switch; at least one backup charge, in particular a capacitor, placed on a second branch parallel with the contacts of the mechanical switch and couplable with/decouplable from the mechanical

switch by means of a second static switch; and an electronic control unit suitable to produce at least one control cycle of said first static switch and of said second static switch to extinguish the arc that forms between said contacts following opening under load of the mechanical switch.

[0027] The invention will now be described with particular reference to the accompanying figures, which represent a non-limiting preferred embodiment thereof, wherein:

- > Figures 1 and 2 show hybrid switches produced according to prior art techniques;
- > Figure 3 shows a hybrid switch produced according to the dictates of the present invention;
- > Figure 4 shows a variant of the switch in Figure 3.

[0028] The hybrid switch 1 shown in Figure 3 includes a first mechanical switch 2 (of known type, in particular electro-mechanical) with a first contact 2a connected to a first electrical line 4 and a second contact 2b connected to a second electrical line 6.

[0029] The hybrid switch 1 also includes a first unidirectional semiconductor static switch 9, interposed between the contacts 2a and 2b and produced, in the example of embodiment shown, by an IGCT.

[0030] The switch 9 is therefore placed in a first branch R1 parallel with the contacts 2a, 2b of the mechanical switch 2. A bypass diode 11 is placed with the cathode connected to the contact 2a and the anode connected to the contact 2b.

[0031] The electrical connection that places the contact 2a, the cathode of the diode 11 and the anode of the switch 9 in communication is produced to have a low inductance value. Analogously, the electrical connection that places the anode of the diode 11, the cathode of the switch 9 and the contact 2b in communication is produced to have a low inductance value.

[0032] The hybrid switch 1 also includes an oscillating inductive-capacitive circuit 13 wherein the inductive and capacitive elements are placed in series with one another.

[0033] The oscillating inductive-capacitive circuit 13 is placed in series with a second unidirectional static switch 16 (which in the example of embodiment shown is produced by a thyristor 16a and a diode 16b placed in series with each other) which constitute, as a whole, a branch R2 in parallel with the mechanical switch 2.

[0034] In greater detail, the oscillating circuit 13 includes a capacitor 15 (backup charge) with a first terminal (+) connected to the electrical line 6 and a second terminal (-) connected to a first terminal of an inductor 17, having in turn a second terminal connected to the electrical line 4 through the interposition of the second static switch 16.

[0035] A dissipation resistor 22 is placed in parallel with the capacitor 15 through the interposition of a third unidirectional static switch 24 produced, in the example

shown, by a component with controllable voltage (in the example of embodiment shown the third static switch is produced using an IGCT).

[0036] The resistor 22 is used to dissipate the magnetic energy present in the circuit, which is interrupted by opening the switch 2, said energy being transferred to the capacitor 15 when the first static switch 9 is opened.

[0037] Moreover, a fourth unidirectional static switch 18 is interposed between the second terminal of the inductor 17 and the first terminal of the capacitor 15. A diode 19 is placed in series with the static switch 18.

[0038] The first electrical line 4 is connected to a first polarity (+) of a direct voltage source Vcc so that a first terminal of the fourth static switch is connected to a reference voltage, the second electrical line 6 feeds a first terminal of a load 26 having a second terminal connected to a second polarity (-) of the direct voltage source Vcc through an electrical return line 28. A bypass diode 30 is placed in parallel with the charge 26 between the lines 6 and 28. The bypass diode 30 has the task of preventing inversion of the voltage on the load 26; although the presence of this diode 30 is not essential, it makes the switch-off time of the hybrid switch 1 (seen from the generator, i.e. from the voltage source Vcc) independent from any high inductance of the load 6.

[0039] The hybrid switch 1 is controlled by an electronic control unit 35, which is suitable to control switching of the static switches 9, 16, 24 and 18 and of the mechanical switch 2.

[0040] In use, to effect opening of the mechanical switch 2, the electronic control unit controls the value of the current Ic that is currently carried by the mechanical switch.

[0041] If this current Ic is considered low (i.e. below a threshold value: $I_c < I_{soglia}$) the operations to open the hybrid switch 1, as controlled by the electronic control unit 35, are - according to one operating mode - as follows:

- a) the mechanical switch 2 is controlled for its opening;
- b) simultaneous to the operations a), the static switch 9 is controlled for its closing so that the current carried by the mechanical switch 2 is diverted to the static switch 9 as soon as the mechanical contacts of 2 separate and an arc voltage starts to develop between the terminals 2a and 2b of the parallel branch R1. This diversion of the current reduces the voltage between the contacts 2a, 2b of the mechanical switch 2 almost immediately extinguishing the electrical arc therebetween.
- c) the electronic switch 16 is maintained open so that the branch R2 remains disconnected from the mechanical switch 2 during execution of the operations a) and b). During the operations of c), the third static switch 24 and the fourth static switch 18 are maintained open.
- d) The static switch 9 is opened.

[0042] In particular, the electronic control unit 35 controls closing of said first static switch 9 according to step b) for a time interval T that takes account of three factors, these being:

- a first time interval t1, corresponding to the delay between the beginning of the control to open the mechanical switch 2 and the actual start of the movement to detach the contacts from one another. The interval t1 is variable, according to the type of mechanical switch, from a few tens of millisecond to a few milliseconds; during this time interval the static switch 9, controlled to close, passes to conduction state in a few microseconds;
- a second time interval t2 which allows the current carried by the mechanical switch 2 to pass to the static switch 9 which is already in conduction state, as the arc voltage at the ends of the mechanical switch 2 (which is completing its movement to open the contacts) is much greater than the voltage in conduction state of the static switch 9 (a few volts); and
- a third time interval t3 which takes account of the time required to extinguish the current in the static switch 9.

[0043] If the current Ic carried by the hybrid switch 1 is high (i.e. over a threshold value: $I_c > I_{soglia}$) the operations above are not possible as the static switch 9 would not be capable of extinguishing a current above Isoglia without being irreparably damaged; therefore, the operations to open the hybrid switch 1 as controlled by the electronic control unit 35 according to a different operating mode are as follows:

- a) the mechanical switch 2 is controlled for opening;
- b) the electronic switch 9 is simultaneously closed so that the current previously carried by the mechanical switch 2 is diverted - for an extremely limited time interval- to the static switch 9 of the parallel branch R1 - this fact considerably reduces the voltage between the contacts 2a, 2b of the mechanical switch 2 starting the process to extinguish the arc between the contacts 2a, 2b; (it can be noted how the steps illustrated here are identical to those described previously);
- c) after a pre-established time interval T9 from closing of the switch 9 (operation b), the length of which is a function of the delay in opening the mechanical switch 2, the second static switch 16 is closed so that the charge stored in the capacitor 15 (which is kept charged) produces a current pulse sent toward the contacts 2a, 2b and having the opposite direction to the current Ic which is interrupted, thus extinguishing the arc completely.

[0044] Subsequent to the operations in c), the voltage at the end of the first terminal of the capacitor 15 (which when loaded and disconnected has a positive value) is

inverted (charge reversal) due to the current coming from the mechanical switch 2 being opened which has the opposite direction to that of the pulse current I_r . To contrast this phenomenon of charge reversal, the fourth static switch 18 is closed, injecting at the ends of the capacitor 15 a current that re-establishes the positive polarity at the ends of the first terminal thereof.

[0045] Closing of the fourth static switch 18 allows the direction of the charge to be reversed again, simultaneously minimizing the time to restore the initial charge and the dissipated power.

[0046] The hybrid switch 1 also provides considerable advantages during the closing operation, in particular if it takes place in the presence of a short circuit (short circuit closing). In this case the closing process of the hybrid switch 1 is as follows:

- a. the static switch 9 is controlled for closing and the current carried by the static switch is monitored in order to check whether it has fault current characteristics (i.e. high current values and/or current derivative values);
- b. if the current has fault current characteristics, the control unit 35 inhibits closing of the mechanical switch 2 and proceeds with immediate opening of the static switch 9;
- c. if no fault conditions are detected, the electronic control unit 35 lets a first time interval T_r elapse which allows the current carried by the static switch 9 to reach a steady state value; at the end of this first time interval T_r the mechanical switch 2 is closed;
- d. the electronic control unit 35 lets a second time interval T_c elapse from closing of the mechanical switch (T_c closing, corresponding to the time required to execute closing of the mechanical switch) so that the current is transferred from the static switch 9 to the mechanical switch 2;
- e. after a third time interval (bounce) which also takes account of the mechanical bouncing characteristic of the mechanical switch during closing, the current is transferred completely to the mechanical switch 2 and current no longer passes through the static switch 9.

[0047] In the case of closing the process illustrated above makes it possible to prevent any arcs during closing (irrespective of whether or not bouncing occurs) and to drastically limit the fault current in the case of short circuit closing.

[0048] All the advantages described above can also be achieved when the current to be interrupted can flow in both directions inside the mechanical switch 9; in this case, the first static switch 9 must be of the bidirectional type, as shown in the preferred embodiment indicated in Figure 4.

[0049] Therein the diode 11 has been replaced by the diode bridge 11p constituted by the diodes 11a, 11b, 11c, 11d, wherein:

- > the diodes 11a, 11c have anodes connected to each other and connected to a conductor which is in turn connected to the cathode of the second static switch 16 which, unlike what is shown in Figure 3, is not connected directly to the first contact 2a of the mechanical switch 2;
- > the diodes 11d, 11b have cathodes connected to each other and connected to the electrical line 6;
- > the cathode of the diode 11a and the anode of the diode 11d are connected to the first contact 2a of the mechanical switch 2;
- > the cathode of the diode 11c and the anode of the diode 11b are connected to the second contact 2b of the mechanical switch 2.

[0050] In this way, the diode bridge (11p) has a first I and a second II terminal connected to the first and to the second contact 2a, 2b of the mechanical switch 2; the first static switch 9 is interposed between third III and fourth IV terminals of the diode bridge 11p.

[0051] In the configuration in Figure 4, when the mechanical switch 2 is opened the current passing there-through from the contact 2a to the contact 2b will pass through the diode 11a, the static switch 9 and the diode 11b when this flows according to a first direction; in the case in which the current flows in the opposite direction (i.e. from 2b to 2a) it will pass through the diode 11c, the first static switch 9 and the diode 11d in this order.

[0052] It is pointed out how the current that flows in the first static switch 9 always flows in the same direction, irrespective of the direction it takes in the mechanical switch 2.

[0053] For this reason the opening operations take place according to the operations set forth above, which for the sake of simplicity are not repeated.

Claims

1. Hybrid switch **characterized in that** it includes:

- a mechanical switch (2);
- at least a first static switch (9) placed on a first branch (R1) parallel with the contacts (2a, 2b) of the mechanical switch (2);
- at least one backup charge (15), in particular a capacitor, placed on a second branch (R2) parallel with the contacts (2a, 2b) of the mechanical switch (2) and couplable with/decouplable from the mechanical switch (2) through a second static switch (16); and
- an electronic control unit (35) suitable to execute at least one control cycle of said first static switch (9) and of said second static switch (16) to extinguish the arc that forms between said contacts (2a, 2b) subsequent to opening under load of the mechanical switch (2).

2. Switch as claimed in claim 1, wherein the opening operations of the hybrid switch (1) as controlled by the electronic control unit (35) according to a first operating mode, are as follows:

a) the mechanical switch (2) is opened;
 b) the first static switch (9) is closed so that the current carried by the mechanical switch (2) is diverted to said first static switch (9) to reduce the voltage between the contacts of the mechanical switch (2) starting the process to extinguish the arc between said contacts (2a, 2b); and
 c) after a pre-established time interval (T9) with respect to step b) the second static switch (16) is closed so that the charge stored in said backup charge (15) produces a pulse directed toward said contacts (2a, 2b) and have the opposite direction to the current (Ic) that is interrupted, thereby causing complete extinguishing of the arc.

3. Switch as claimed in claim 2, wherein the value of said pre-established time interval (T9) is a function of the delay in opening of the mechanical switch (2).

4. Switch as claimed in claim 2, wherein said inductor (17) and said backup charge, produced by at least one capacitor, are placed in series with each other.

5. Switch as claimed in claim 2, wherein there is provided at least a third static switch (18) interposed between a voltage source and a terminal (+) of said backup charge (15); said third static switch (18) being closed to supply a current to said terminal of said backup charge (15) and invert the polarity at the ends of said terminal.

6. Switch as claimed in claim 2, wherein said third static switch (18) is closed subsequent to the operations of said step c).

7. Switch as claimed in claim 2, wherein said third static switch (18) is connectable to said voltage source through said second static switch (16).

8. Switch as claimed in claim 2, wherein the electronic control unit (35) controls the current flowing through the mechanical switch and executes the operations a), b) and c) if this current exceeds a threshold value (Isoglia).

9. Switch as claimed in claim 1, wherein the operations to open the hybrid switch (1), as controlled by the electronic control unit (35) according to a second operating mode, are as follows:

d) the mechanical switch (2) is controlled for opening;

e) simultaneous to the operations d), the first static switch (9) is controlled for closing so that the current previously carried by the mechanical switch (2) is diverted to the first static switch (9) reducing the voltage between the contacts (2a, 2b) of the mechanical switch (2) extinguishing the arc between the contacts (2a, 2b) of said mechanical switch (2);
 f) the second static switch (16) is maintained open so that the second branch (R2) is maintained disconnected from the mechanical switch (2);
 g) the first static switch (9) is subsequently opened.

10. Switch as claimed in claim 9, wherein the electronic control unit controls the current flowing through the mechanical switch and executes said operations d), e), f) and g) if the current is below a threshold value (Isoglia).

11. Switch as claimed in claim 9, wherein said electronic control unit controls closing of said first static switch (9) according to step e) for a time interval that takes account of three factors, these being:

- a first time interval t1, corresponding to the delay between the beginning of the control to open the mechanical switch (2) and the actual start of the movement to detach the contacts from one another;
- a second time interval t2 which allows the current carried by the mechanical switch (2) to pass to said static switch (9) which is in conduction state;
- a third time interval t3 which takes account of the time required to extinguish the current in the first static switch (9).

12. Switch as claimed in claim 1, wherein the operations to close the hybrid switch (1) as controlled by the electronic control unit (35) are as follows:

f. said first static switch (9) is closed and the current carried by the first static switch is monitored in order to check whether it has fault current characteristics;
 g. if the current has fault current characteristics, said control unit (35) inhibits closing of the mechanical switch (2) and proceeds with immediate opening of the first static switch (9);
 h. if no fault conditions are detected, said electronic control unit (35) lets a first time interval Tr elapse to allow the current carried by the first static switch (9) to reach a steady state value; at the end of said first time interval Tr the mechanical switch (2) is closed;
 i. the electronic control unit (35) lets a second

time interval T_c elapse from closing of the mechanical switch (2) so that the current is transferred completely from the static switch (9) to the mechanical switch (2).

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13. Switch as claimed in claim 1, wherein said switch is interposed between a terminal of a direct voltage source (V_{cc}) and a first input terminal of a load (26) having at least a second input terminal; a bypass diode (30) being placed in parallel with said load (26). 10

14. Switch as claimed in claim 1, wherein there is provided a diode (11) placed in parallel with the first static switch (9) and being part of said first branch (R1). 15

15. Switch as claimed in claim 1, wherein there is provided a diode bridge (11p) having a first (I) and a second (II) terminal connected to the first (2a) and to the second (2b) contact of said mechanical switch; said first static switch (9) being interposed between third (III) and fourth (IV) terminals of the diode bridge (12p); said second static switch (16) having a terminal connected to a terminal (III) of said diode bridge (12p). 20
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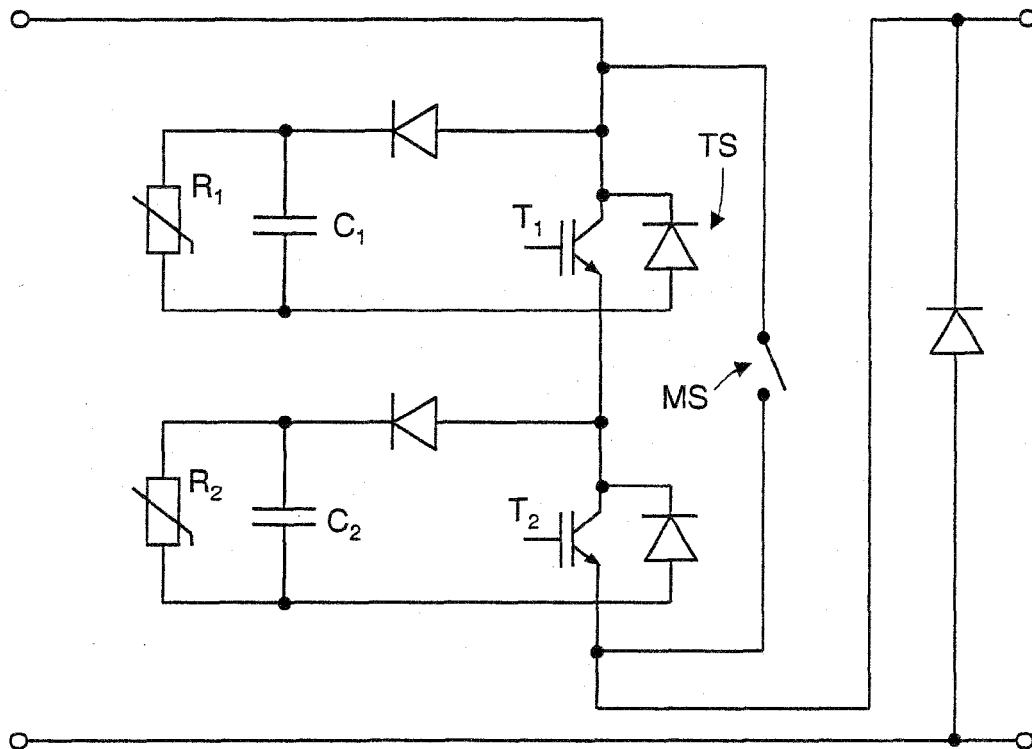


Fig.1

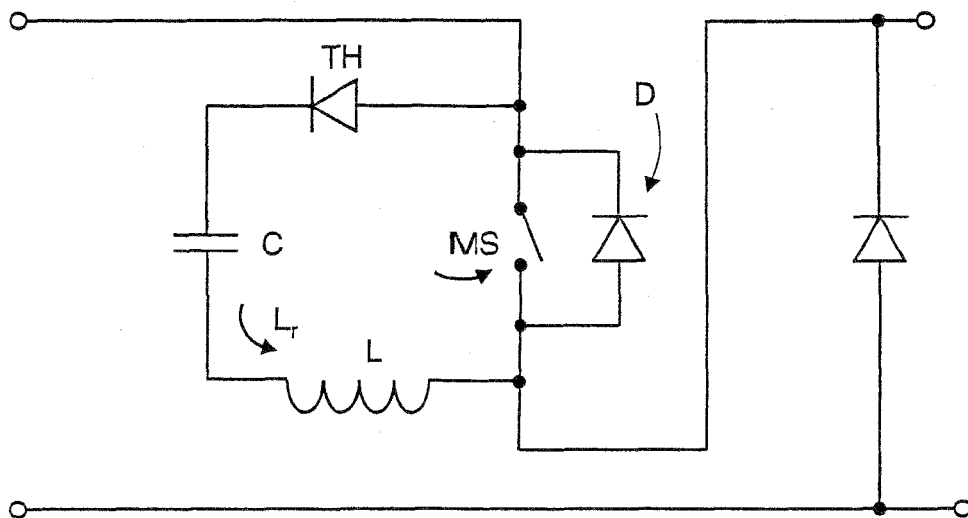


Fig.2

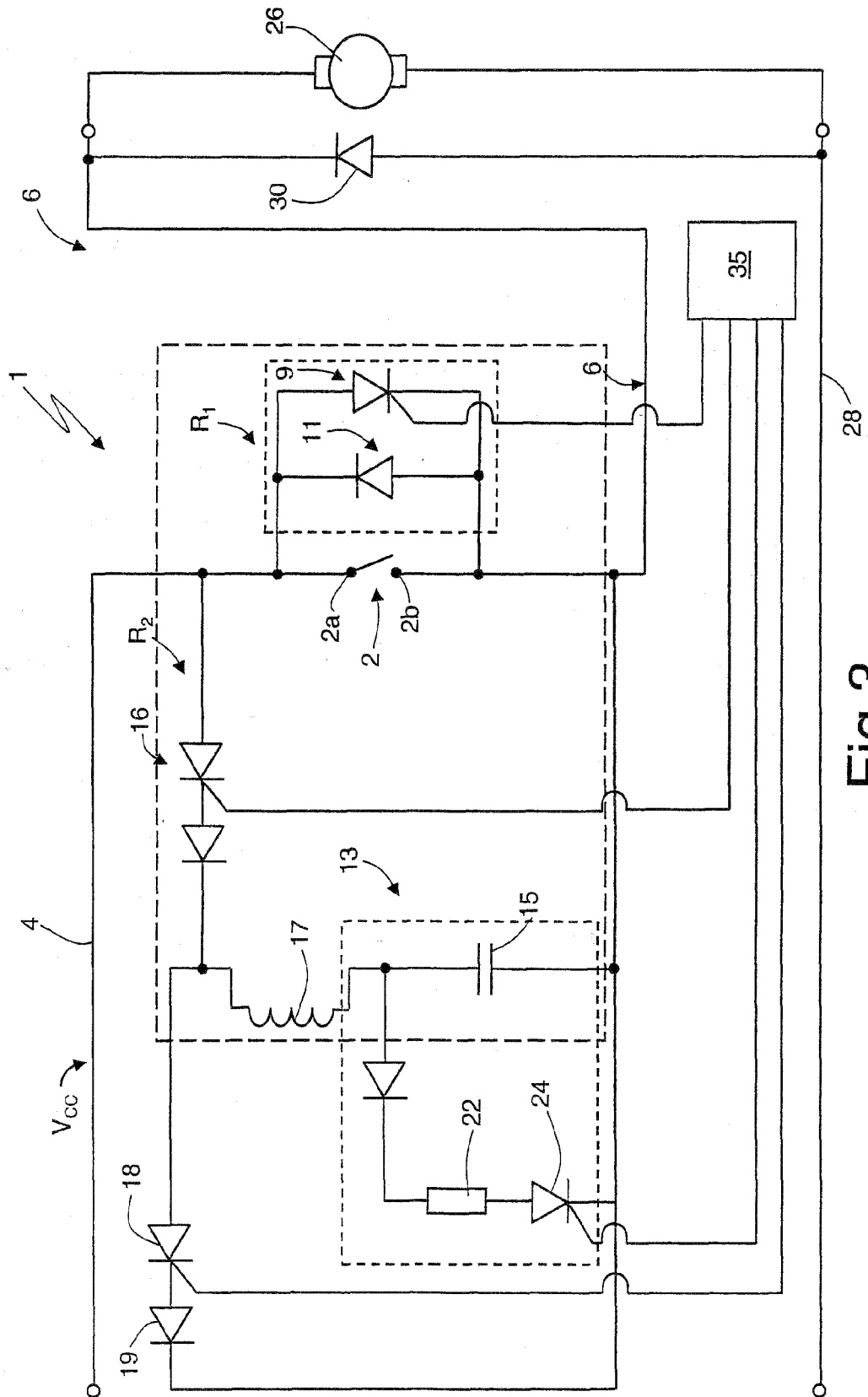


Fig.3

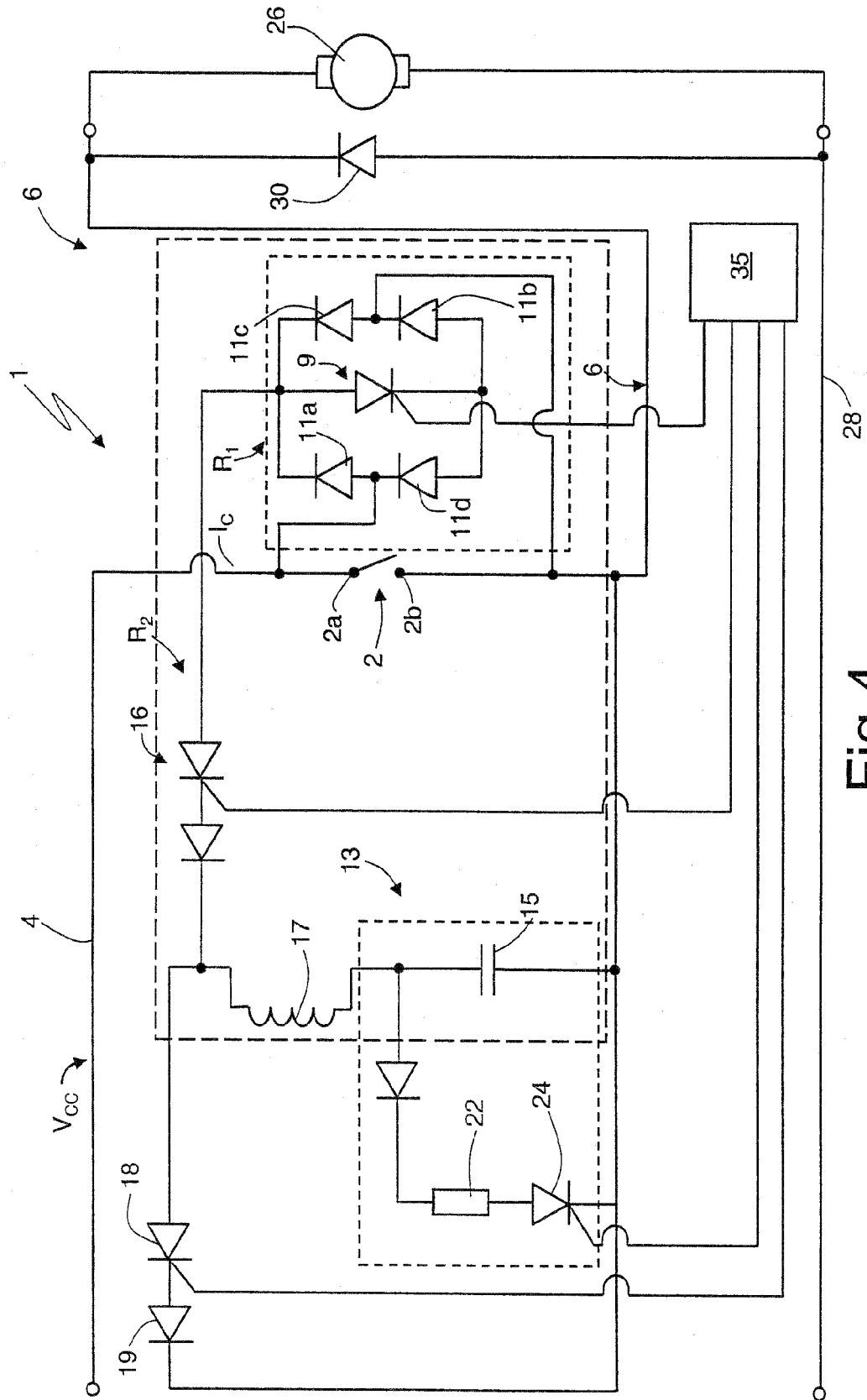


Fig. 4



European Patent
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EUROPEAN SEARCH REPORT

Application Number
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Place of search		Date of completion of the search	Examiner
Munich		8 October 2007	MAEKI-MANTILA, M
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**ANNEX TO THE EUROPEAN SEARCH REPORT
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