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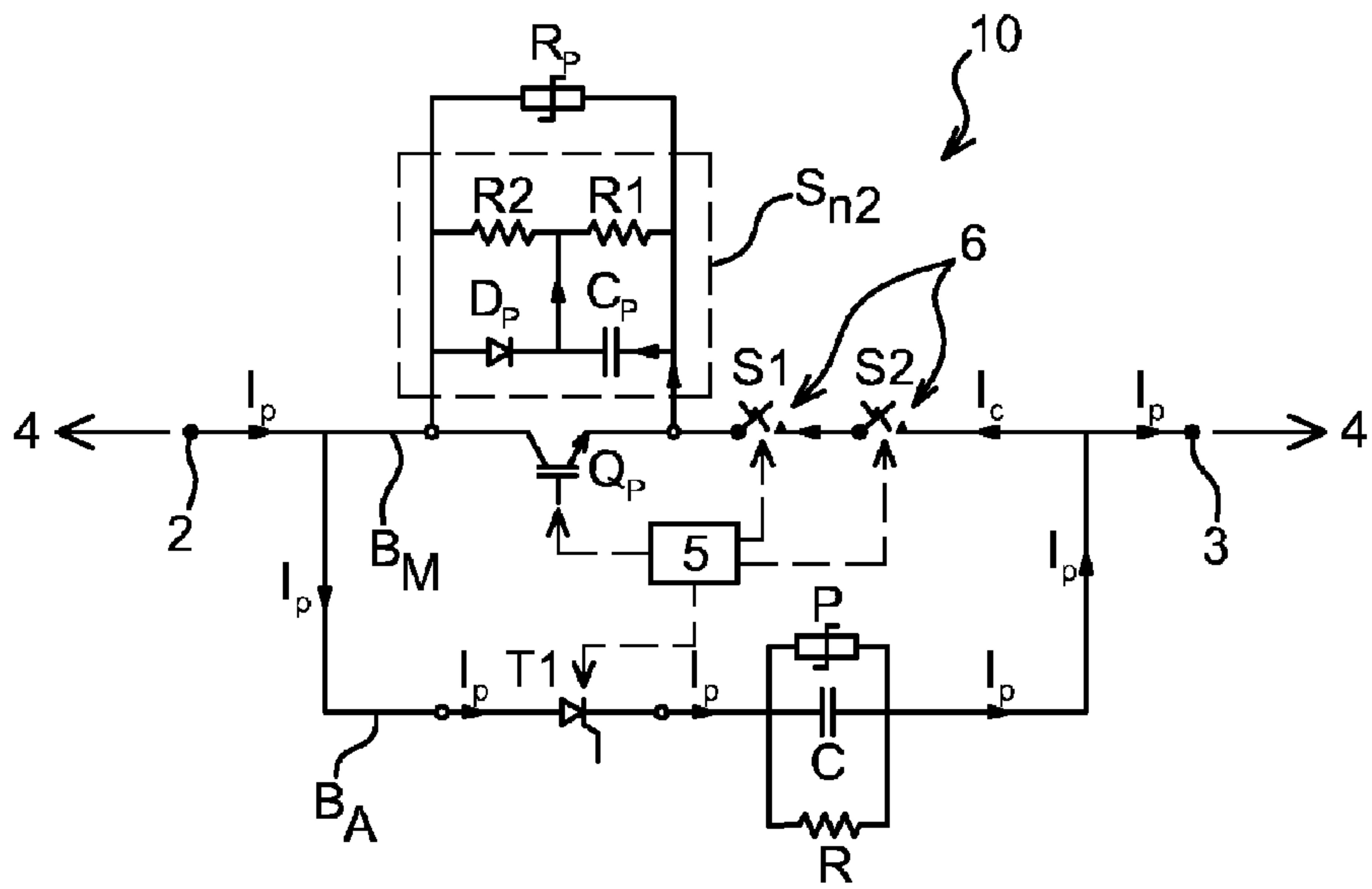

FIG. 3a

(57) Abrégé/Abstract:
A circuit-breaker device (10), comprising a main branch (B_M) and an auxiliary branch (B_A) electrically in parallel with the main branch, wherein the main branch comprises at least one mechanical switch-disconnector (SI, S2) in series with a breaker cell constituted of at least one semiconductor switch (Q_P), and a snubber circuit (Sn2) in parallel with the at least one breaker cell, the snubber circuit including an energy storage element (C_P), wherein the mechanical switch-disconnector (S1, S2) is switchable to selectively allow current to flow in the main branch in a first mode of operation or commutate current from the main branch to the auxiliary branch in a second mode of operation, characterized in that the snubber circuit (Sn2) further comprises a bleeder resistor (R2) arranged to create a counter current in the main branch when current is commutated from the main branch to the auxiliary branch by discharging the energy storage element (C_P).

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(54) Title: DC CIRCUIT BREAKER WITH COUNTER CURRENT GENERATION

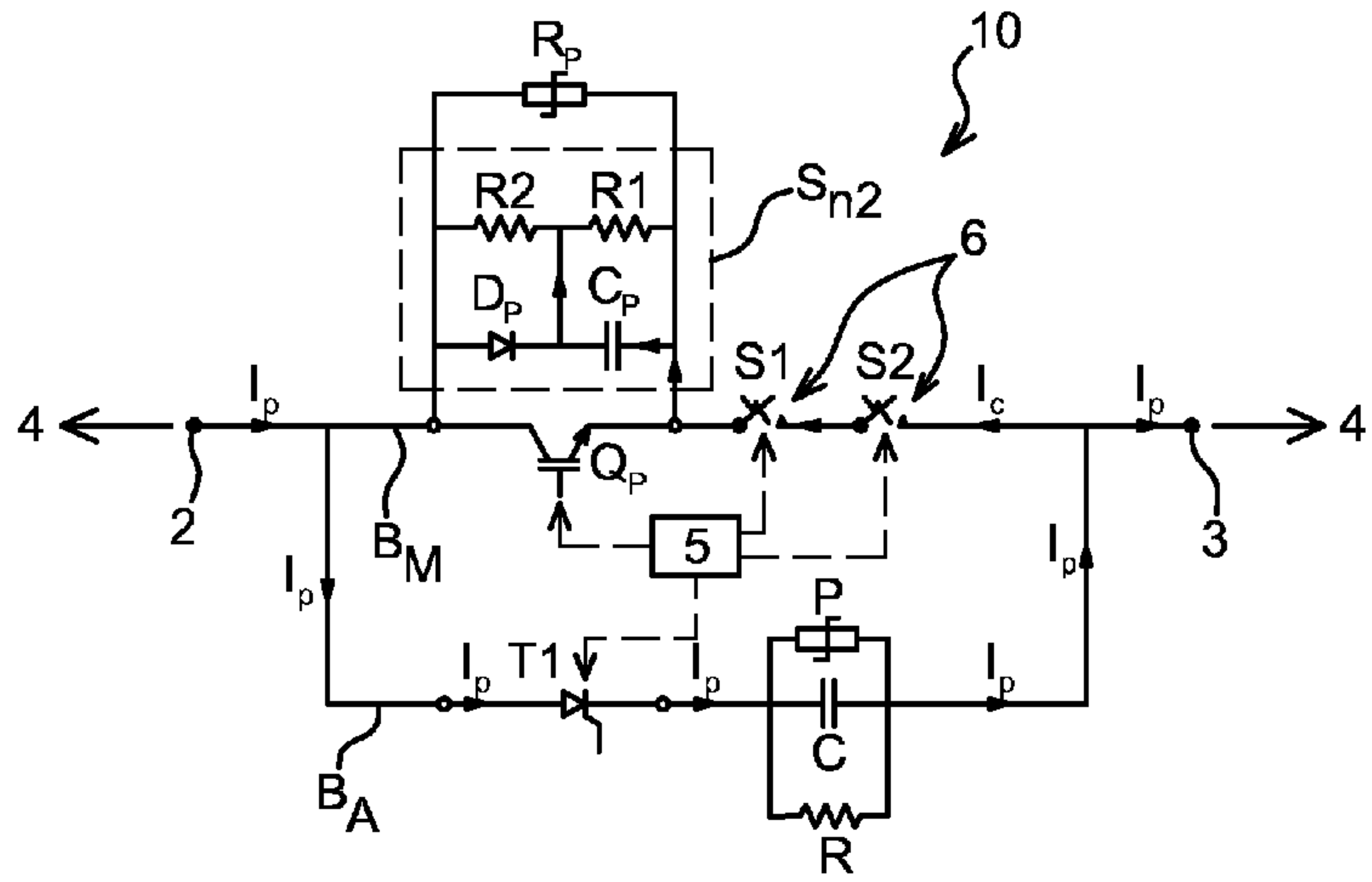

FIG. 3a

(57) Abstract: A circuit-breaker device (10), comprising a main branch (B_M) and an auxiliary branch (B_A) electrically in parallel with the main branch, wherein the main branch comprises at least one mechanical switch-disconnector (SI, S2) in series with a breaker cell constituted of at least one semiconductor switch (Q_P), and a snubber circuit (Sn2) in parallel with the at least one breaker cell, the snubber circuit including an energy storage element (C_P), wherein the mechanical switch-disconnector (S1, S2) is switchable to selectively allow current to flow in the main branch in a first mode of operation or commutate current from the main branch to the auxiliary branch in a second mode of operation, characterized in that the snubber circuit (Sn2) further comprises a bleeder resistor (R2) arranged to create a counter current in the main branch when current is commutated from the main branch to the auxiliary branch by discharging the energy storage element (C_P).

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DC CIRCUIT BREAKER WITH COUNTER CURRENT GENERATION

DESCRIPTION

TECHNICAL FIELD

The invention relates to a circuit-breaker device for use in high voltage direct current (HVDC) power transmission.

STATE OF THE ART

Grid operators increasingly use high voltage direct current (HVDC) to carry high power efficiently over long distances. A prime reason is that for such high power long-distance links, direct current (DC) is superior to alternating current (AC) because it can transmit power without capacitive or inductive losses.

DC converter stations also improve the stability of the associated AC networks by decoupling the frequency and phase of those networks. HVDC links are therefore very useful in stabilizing grids which are challenged by a growing contribution of power from distributed and intermittent sources such as wind or solar energy.

A key element in power networks is the circuit breaker. Its role is to protect the network, preventing failures and blackouts by rapidly cutting the current in a malfunctioning element (following a lightning strike, or the breakage of an undersea cable, for example). In this way it isolates the fault from the rest of the grid. Circuit breakers are vital to protect complex interconnected grids, be they AC or DC.

In AC networks, the current is periodically driven through zero (100 times a second for a 50 Hz network), and current zero is the ideal instant to interrupt.

But in DC networks, there is no natural current zero and one major technical challenge is fault current that does not stop rising.

In the absence of current zero, electrical arcs are created between contacts which are separated by switches of the circuit breaker. This can erode and degrade the contacts, thereby adversely affecting the dielectric withstand and reducing the lifetime of the switches.

The DC breaker with elements that are able to create an artificial current zero has therefore been developed.

As shown on figure 1, and for instance described in the article from Dag Andersson Dr. and Anders Henriksson, "Passive and Active DC Breakers in the Three Gorges – Changzhou HVDC Project" (Cigré International Conference on Power Systems, Wuhan, China, 3-5 September, 2001, Page 391), such artificial current zero can be achieved by adding an LC oscillating circuit in parallel to a circuit breaker B. Here the LC circuit comprises a series arrangement of an inductor L, an interrupter I and a capacitor C which is permanently pre-charged.

The DC breaker of figure 1 comprises three branches in parallel: a low-impedance branch with the breaker B (main branch) where current flows in steady state, an auxiliary branch with the LC circuit and an energy absorber branch with a surge arrester P.

The switching scenario is a two-step process.

- Step 1: In the closed position of the breaker B, the current flows through the main branch, the auxiliary and energy absorber branches playing no role. On a trip order, to initiate current commutation from the main branch to the auxiliary branch, the breaker's contacts are separated while current still flows through the main branch. An arc of increasing length is thereby drawn between the breaker's contacts. When the contacts are sufficiently separated, the interrupter I of the auxiliary branch is closed. The pre-charged capacitor C discharges through the inductor L and the breaker B with a frequency imposed by the capacitance and inductance of this oscillating circuit. If the voltage of the capacitor is high enough, the discharge current exceeds the DC current, current crosses zero and the current in the main branch is interrupted in less than one period. Otherwise the discharge initiates current oscillations in the loop formed by the main and auxiliary branches. The oscillating current increases and finally exceeds the DC current that is to be interrupted. Now the current flowing through the main branch has zero crossings and the breaker can interrupt the current.

- Step 2. When the arc current is interrupted, current now only flows in the auxiliary branch. The energy in the line (or cable) is still too high, and it continues charging up the capacitor. When the knee point voltage of the surge arrester is reached, it starts conducting, absorbs energy and clamps the voltage. This voltage opposes the current flow through the circuit breaker until the line has no more energy which corresponds to a zero current. Voltage drops to the knee point voltage of the surge arrester and current is definitely interrupted.

Another example of a DC breaker with artificial current zero creation by means of a LC circuit is shown on figure 2 and described in the article from Yeqi Wang and Rainer Marquardt, « A fast switching, scalable DC-Breaker for meshed HVDC-Super-Grids », PCIM-Europe, 20-22 May 2014.

In the closed position of the two breakers B_{in}, B_{out} on the main branch, the capacitor C_{PG} is charged to the network voltage. When this circuit breaker is set to interrupt, a mechanism opens the breakers Bin and Bout, thereby creating an electric arc in both breakers. When the contact separation is large enough to ensure voltage stability, the thyristor T_{PG} is closed and initiates a current in the loop formed by the capacitor C_{PG} (precharged) and the inductor L_{PG}. When the current tries to reverse (i.e. after a half period), thyristors turn off naturally without the need for a turn-off command. After thyristors blocking, the capacitor C_{PG} ends up with roughly the same charge, but the voltage is reversed. A second current oscillation is then initiated between the capacitor C_{PG} and inductances L_{in} and L_{out} external to the circuit breaker. The high inrush current of the part of the network on the left and right of the circuit breaker towards the capacitor C_{PG} creates a zero current in the breaker which is on the side of the fault. In case the inrush current was much higher than the current flowing at the instant of switching, diodes D_{in}, D_{out} in parallel with the breakers allow current to flow without re-ignition of the arc and branches labeled DB close the circuit to keep the loop inductance low and the inrush current high. If the network inductances L_{in}, L_{out} still have magnetic energy, it can be dissipated in the surge arrester VDR_{PG}. The current is reduced to zero and the fault is isolated.

These prior art solutions have the disadvantage of creating a countercurrent which is higher than the current to be cut. Indeed, countercurrent values must exceed the magnitude of kilo amperes for the circuit breaker of figure 1 and ten kilo amperes for the circuit breaker of figure 2. Due to the inductance in the loop in which the current must flow, a certain amount of energy has to be stored which necessitate capacitors of large volume. Such capacitors are especially onerous in that they must be mounted insulated from earth and isolated from each other in the second prior art.

SUMMARY OF THE INVENTION

The invention aims at accelerating arc extinction in a HVDC circuit breaker while overcoming the disadvantage of the prior art solutions. To this purpose, the invention proposes a circuit breaker device comprising a main branch and an auxiliary branch electrically in parallel with the main branch, wherein the main branch comprises at least one mechanical switch-disconnector in series with a breaker cell constituted of at least one semiconductor switch, and a snubber circuit in parallel with the at least one breaker cell, the snubber circuit including an energy storage element, wherein the mechanical switch-disconnector is switchable to selectively allow current to flow in the main branch in a first mode of operation or commutate current from the main branch to the auxiliary branch in a second mode of operation, characterized in that the snubber circuit further comprises a bleeder resistor arranged to create a counter current in the main branch when current is commutated from the main branch to the auxiliary branch by discharging the energy storage element.

Certain preferred but not limiting features of this circuit breaker device are as follows:

- the snubber circuit comprises a diode connected in series with the energy storage element, the bleeder resistor being arranged in parallel with the diode;
- it further comprises a surge arrester in parallel with the at least one breaker cell;

- the auxiliary branch further comprises at least one thyristor in series with a switching-assistance module constituted by the parallel connection of a capacitor, a resistor, and a surge arrester;

The invention further relates to a power system including a transmission line arranged to carry direct current and a circuit-breaker device according to the invention coupled to the transmission line to controllably effecting discontinuation of flow of direct current in the transmission line. The power system may include a High Voltage Direct Current power transmission system.

DESCRIPTION OF THE DRAWINGS

Other aspects, goals, advantages and features of the invention will appear more clearly on reading the following detailed description of preferred embodiments thereof, given by way of non-limiting example and with reference to the accompanying drawing in which:

- figures 1 and 2, already discussed above, show circuit breaker devices of the prior art;
- figures 2a-2c illustrate operating modes of another prior art circuit breaker device;
- figure 2d shows the current commutation from the main branch to the auxiliary branch of the prior art circuit breaker device of figures 2a-2c;
- figure 3a shows a circuit breaker device according to a possible embodiment of the invention;
- figure 3b shows the current commutation from the main branch to the auxiliary branch of the circuit breaker of figure 3a.

DESCRIPTION OF PREFERRED EMBODIMENTS

Figures 2a-2c illustrate operating modes of a prior art circuit breaker device 1 with no countercurrent generation for accelerating arc extinction. Figure 3a shows a circuit breaker device 10 according to a possible embodiment of the invention. As will be apparent from the below description, the circuit breaker device 10 has the same topology as the prior art circuit breaker 1 but with an additional bleeder resistor that allows creating a counter current. For this reason, common elements in the circuit breaker devices 1 and 10 share the same references.

The circuit breaker devices 1, 10 are each adapted to be coupled to a transmission line of a power system, arranged to carry direct current, for controllably effecting discontinuation of flow of direct current in the transmission line. The power system may comprise a High Voltage Direct Current power transmission system.

Each of the circuit breaker devices 1, 10 comprises a main branch B_M in which, in use, the current flows under steady conditions and an auxiliary branch B_A electrically in parallel with the main branch. Each of the main and auxiliary branches B_M, B_A extend between a first and a second terminal 2, 3 which, in use, are connected to a DC electrical network 4.

The main branch B_M comprises at least one mechanical switch-disconnector S1, S2 in series with at least one breaker cell constituted by at least one semiconductor switch Q_P. The at least one mechanical switch-disconnector S1, S2 is for instance a vacuum interrupter. Each semiconductor switch Q_P can, for example, be a silicon-based insulated gate bipolar transistor (IGBT). Alternatively, other types of turn-off semiconductor device such as a JFET, MOSFET or bipolar transistor can be used, as could other wide-band-gap semiconductor materials such as silicon carbide or gallium nitride.

The circuit breaker devices 1, 10 further comprise a switching control unit 5 to control switching of the at least one mechanical switch-disconnector S1, S2 and of the at least one semiconductor switch Q_P.

Hence, by means of the switching control unit 5, the at least one mechanical switch-disconnector S1, S2 is switchable to selectively allow current to flow in the main branch B_M in a first mode of operation or commutate current from the main branch to the auxiliary branch B_A in a second mode of operation.

The main branch B_M further comprises a snubber circuit Sn1, Sn2 in parallel with the at least one breaker cell Q_P. The snubber circuit includes a diode D_P electrically in series with an energy storage element such as a capacitor C_P, itself electrically in parallel with a discharge resistor R1.

The energy storage element C_P controls the rate of increase of the voltage at its terminals when the breaker cell Q_P is switched to the OFF state by the switching control unit 5. The diode D_P prevents violent discharging of the capacitor C_P when the breaker cell Q_P begins to conduct. Finally, the discharge resistor R1 enables slow discharging of the energy storage element C_P.

Hence, the snubber circuit protects the breaker cell to which it is associated by controlling the rate at which the voltage across its terminals increases when it switches from the conducting (ON) state to the non-conducting (OFF) state. This limitation of the rate of voltage increase also has a beneficial effect for switching the current from the main branch to the auxiliary branch, in the sense that it contributes to controlling the di/dt of the current in said branch.

Also electrically in parallel with the breaker cell Q_P is a surge arrester R_P. It is designed to limit the voltage to a value less than the withstand voltage of the breaker cell Q_P.

The auxiliary branch B_A is provided in parallel with the main branch B_M and comprises at least one thyristor T1 in series with a switching-assistance module constituted by the parallel connection of a capacitor C, a resistor R to discharge the capacitor, and a surge arrester P. The switching control module 5 is further configured to switch the at least one thyristor T1 between its non-conducting (OFF) state and its conducting (ON) state.

When the circuit breaker devices 1, 10 switch from the main into the auxiliary branch, the surge arresters RP, P are used one after the other in both branches.

Figure 2a illustrates the first mode of operation with current I_P flowing in the main branch B_M.

Upon appearance of an electrical fault on the network 4, current I_P increases in the main branch B_M. In order to eliminate this fault, current has to be interrupted. Current interruption is performed with the switching control unit 5 implementing the following sequence of operations.

As shown on figure 2b, first the at least one breaker cell Q_P in the main branch B_M is switched off and the current is diverted to the snubber circuit Sn1. The snubber circuit Sn1 limits the rate of rise of voltage and charges its energy storage element C_P until the parallel surge arrester R_P conducts.

In a second step, as shown on figure 2c, the at least one thyristor T1 in the auxiliary branch B_A is switched to its conducting state. Simultaneously, opening of the at least one mechanical switch-disconnector S1, S2 in the main branch is started.

The current is therefore diverted to the auxiliary branch B_A. Figure 2d shows this current commutation from the main branch to the auxiliary branch, with I_M designating the current value in the main branch over time and I_A designating the current value in the auxiliary branch over time.

Following this commutation, the capacitor C in the auxiliary branch B_A gets charged until the parallel surge arrester P conducts. This last surge arrester P limits the voltage to a smaller value than the first surge arrester R_P. The energy storage element C_P of the snubber circuit Sn1 discharges slowly through the parallel discharge resistor R1. Depending on the voltage difference and technology used (highly non-linear transient voltage suppressor versus non-linear surge arrester) a current still passes in the same direction as before the second step through the at least one mechanical switch-disconnector S1, S2 in the main branch B_M of the prior art circuit breaker device 1, and an electrical arc 6 is created.

In order to establish a current zero in the branch and ensure that the arc extinguishes, the invention makes use of the charges stored in the energy storage element C_P of the snubber circuit to generate a counter current in the main branch. As shown on figure 3a which represents the circuit breaker device 10 according to the invention, the snubber circuit Sn2 further comprises a bleeder resistor R2 arranged to create a counter current Ic in the main branch B_M when current is commutated from the main branch to the auxiliary branch by discharging the energy storage element Cp.

Upon complete discharge of the energy storage element Cp, the counter current gets stabilized at zero.

As shown on figure 3a, the bleeder resistor R2 may be arranged in parallel with the diode D_P of the snubber circuit Sn2.

The bleeder resistor R2 may be identical to the discharge resistor R1, but can be chosen smaller to adjust the counter current Ic.

The effect of adding the bleeder resistor R2 on the current in the at least one mechanical switch-disconnector S1, S2 can be seen on figure 3b which represents the current value I_M in the main branch over time and the current value I_A in the auxiliary branch over time. A peak of negative current is observed, of a few tens of amperes but of very low duration (less than a millisecond), which correspond to the counter current Ic created in the main branch B_M. This counter current Ic is of very low value compared to the current to be interrupted, but of sufficient value to create the zero crossing and accelerate extinction of the arc. Lifetime of the contacts of the at least one mechanical switch-disconnector is therefore improved, while the counter-current only necessitates small capacitors to be generated.

CLAIMS

1. A circuit-breaker device (10), comprising a main branch (B_M) and an auxiliary branch (B_A) electrically in parallel with the main branch, wherein the main branch comprises at least one mechanical switch-disconnector (S1, S2) in series with a breaker cell constituted of at least one semiconductor switch (Q_P), and a snubber circuit (Sn2) in parallel with the at least one breaker cell, the snubber circuit including an energy storage element (C_P), wherein the mechanical switch-disconnector (S1, S2) is switchable to selectively allow current to flow in the main branch in a first mode of operation or commutate current from the main branch to the auxiliary branch in a second mode of operation,
characterized in that the snubber circuit (Sn2) further comprises a bleeder resistor (R2) arranged to create a counter current in the main branch when current is commutated from the main branch to the auxiliary branch by discharging the energy storage element (Cp).

2. The circuit-breaker device of claim 1, wherein the snubber circuit (Sn) comprises a diode (Dp) connected in series with the energy storage element (Cp), the bleeder resistor (R2) being arranged in parallel with the diode.

3. The circuit-breaker of any one of claims 1-2, further comprising a surge arrester (R_P) in parallel with the at least one breaker cell.

4. The circuit-breaker of any one of claims 1-2, wherein the auxiliary branch (BA) further comprises at

least one thyristor (T1) in series with a switching-assistance module constituted by the parallel connection of a capacitor (C), a resistor (R), and a surge arrester (P).

5. A power system including a transmission line arranged to carry direct current and a circuit-breaker device according to any one of claims 1-4 coupled to the transmission line to controllably effecting discontinuation of flow of direct current in the transmission line.

6. The power system of claim 5, comprising a High Voltage Direct Current power transmission system.

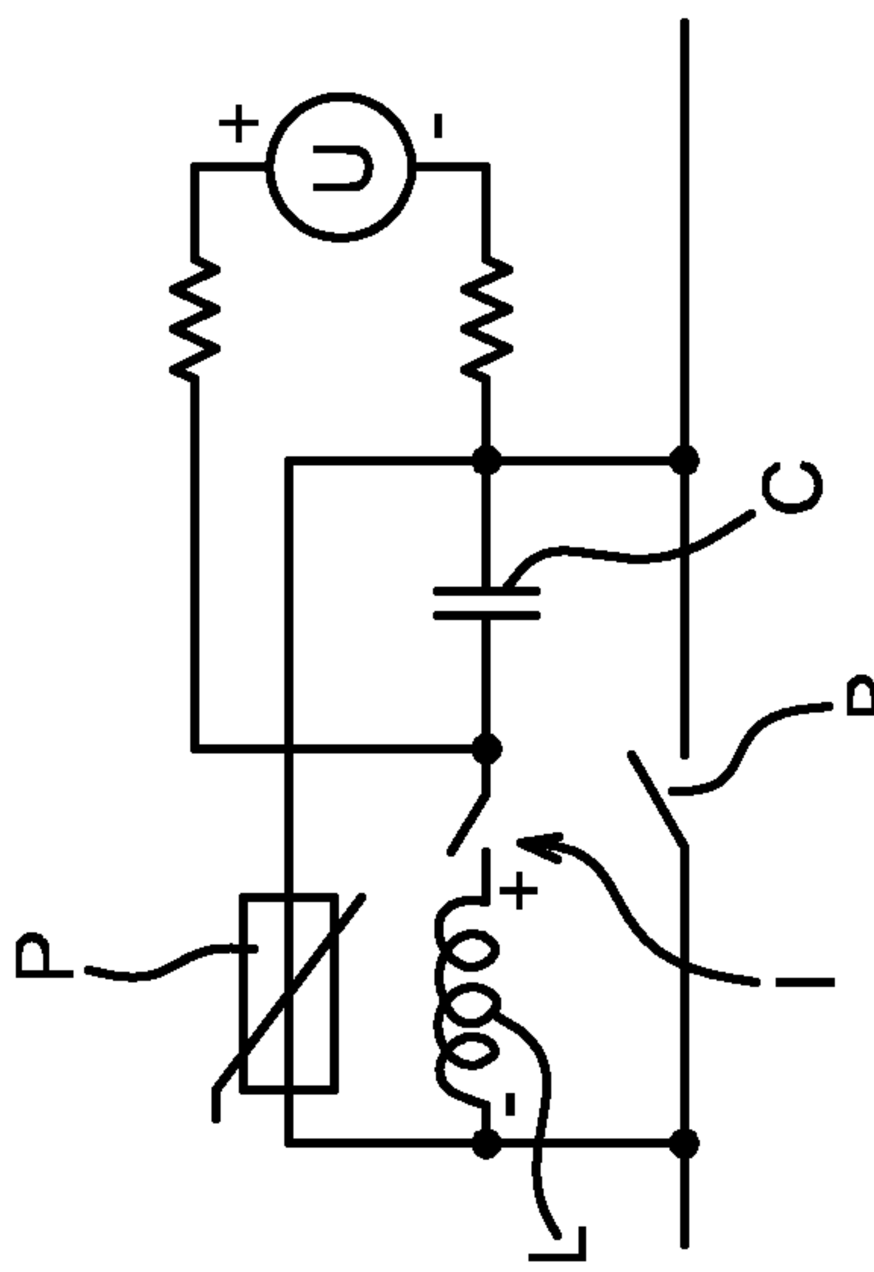
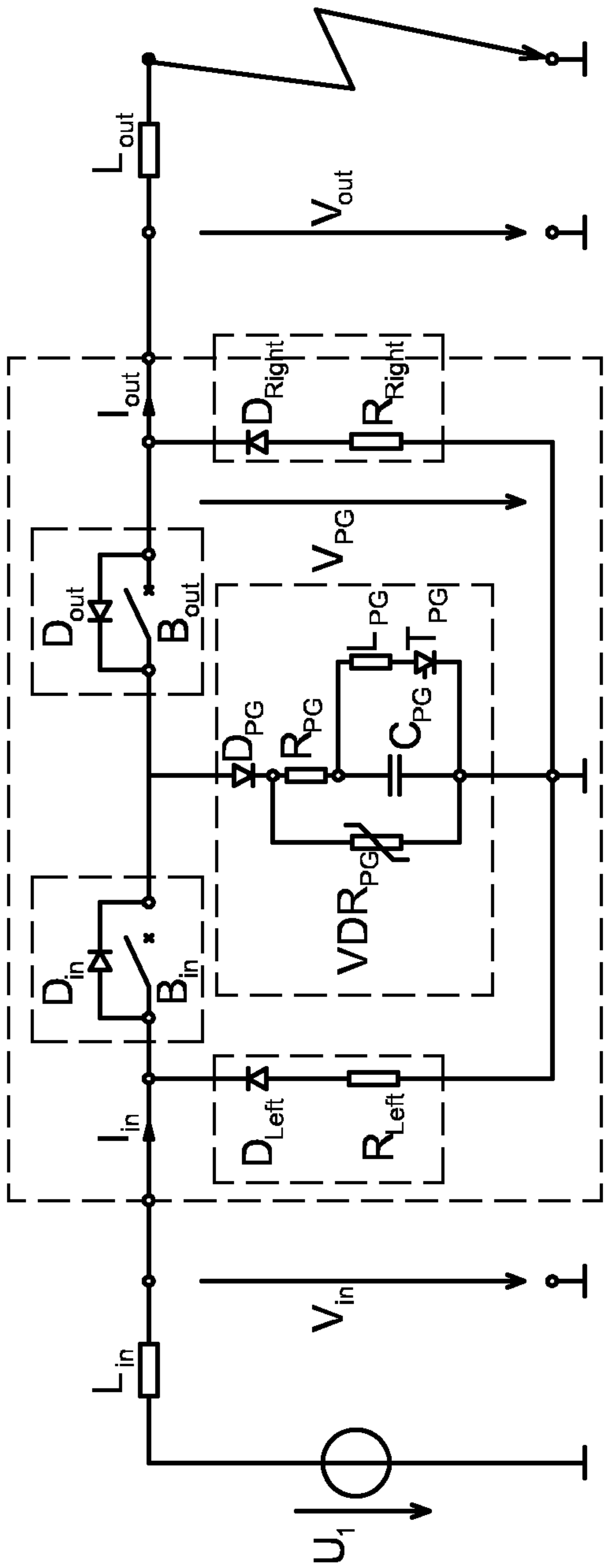

P
C
B
L
I
U
+
-

FIG. 1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V_{out}
I_{out}
D_{Right}
R_{Right}
V_{PG}
D_{out}
B_{out}
L_{PG}
T_{PG}
D_{PG}
R_{PG}
C_{PG}
VDR_{PG}
D_{in}
B_{in}
I_{in}
D_{Left}
R_{Left}
V_{in}
L_{in}
U_1

FIG. 2

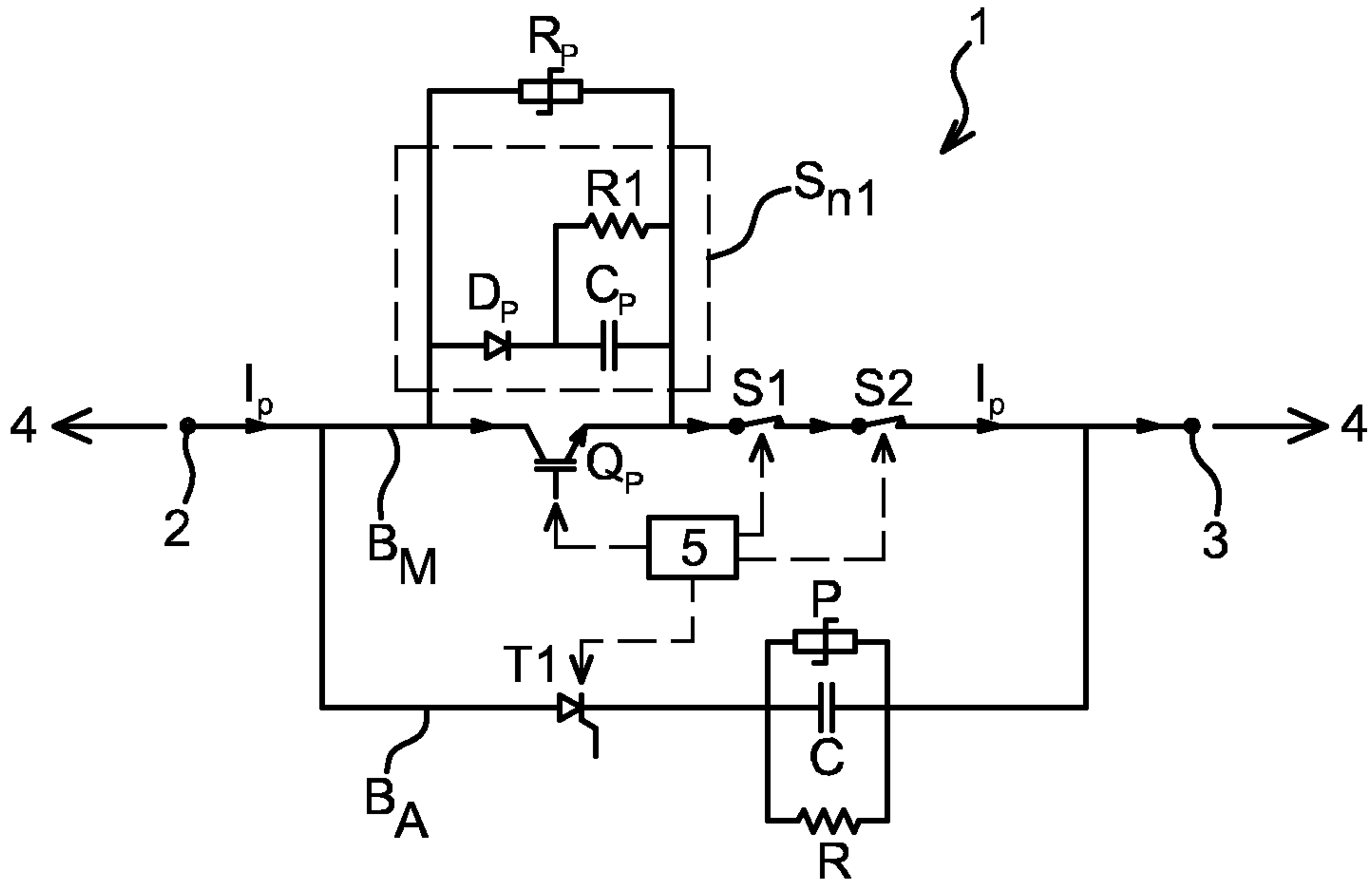

R_P
1
R1
S_n1
D_P
C_P
I_p
S1
S2
I_p
4
4
Q_P
2
B_M
5
3
P
T1
C
B_A
R

FIG. 2a

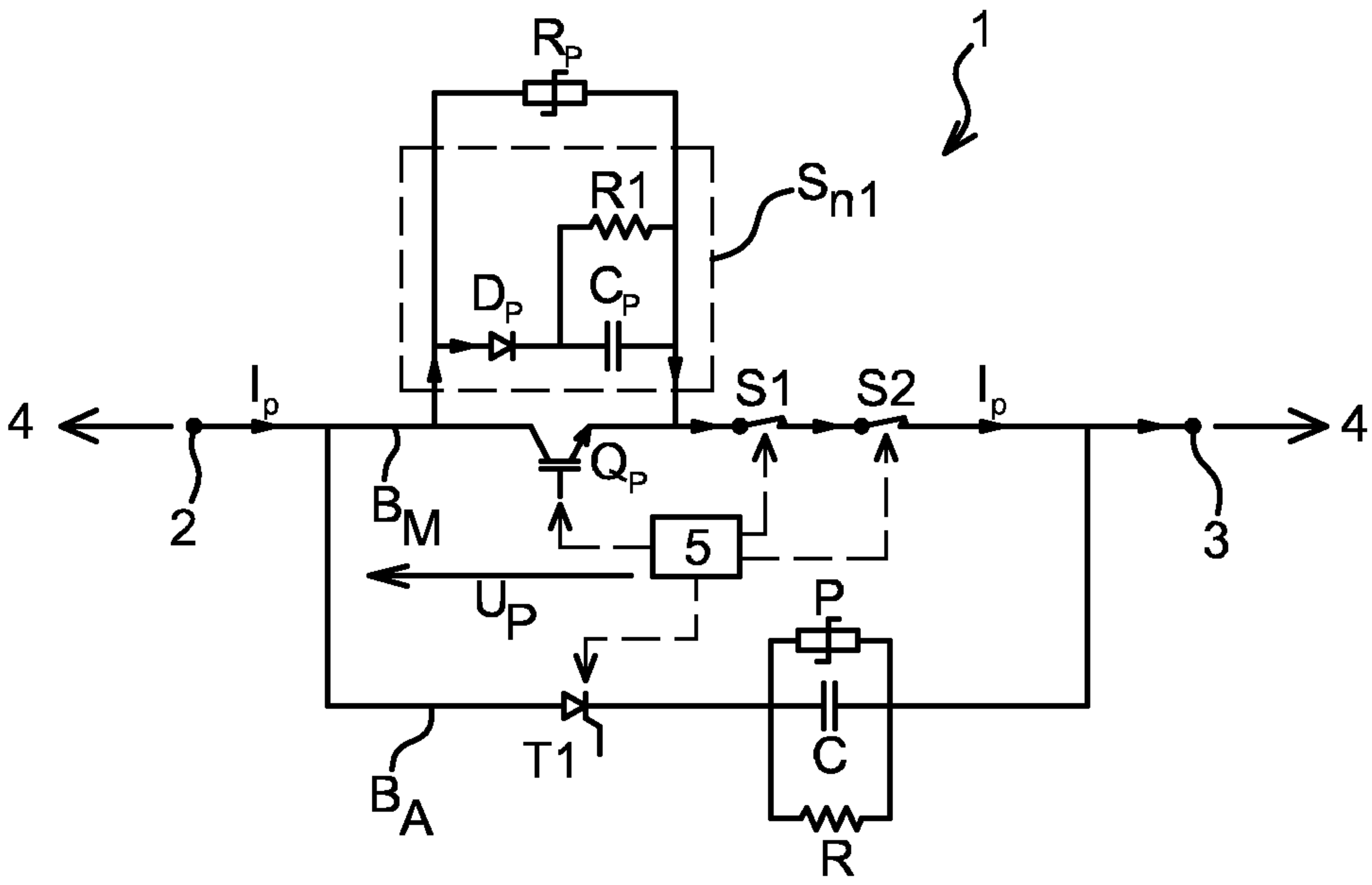

R_P
1
R1
S_n1
D_P
C_P
I_p
S1
S2
I_p
4
4
Q_P
2
B_M
5
3
U_P
P
T1
C
B_A
R

FIG. 2b

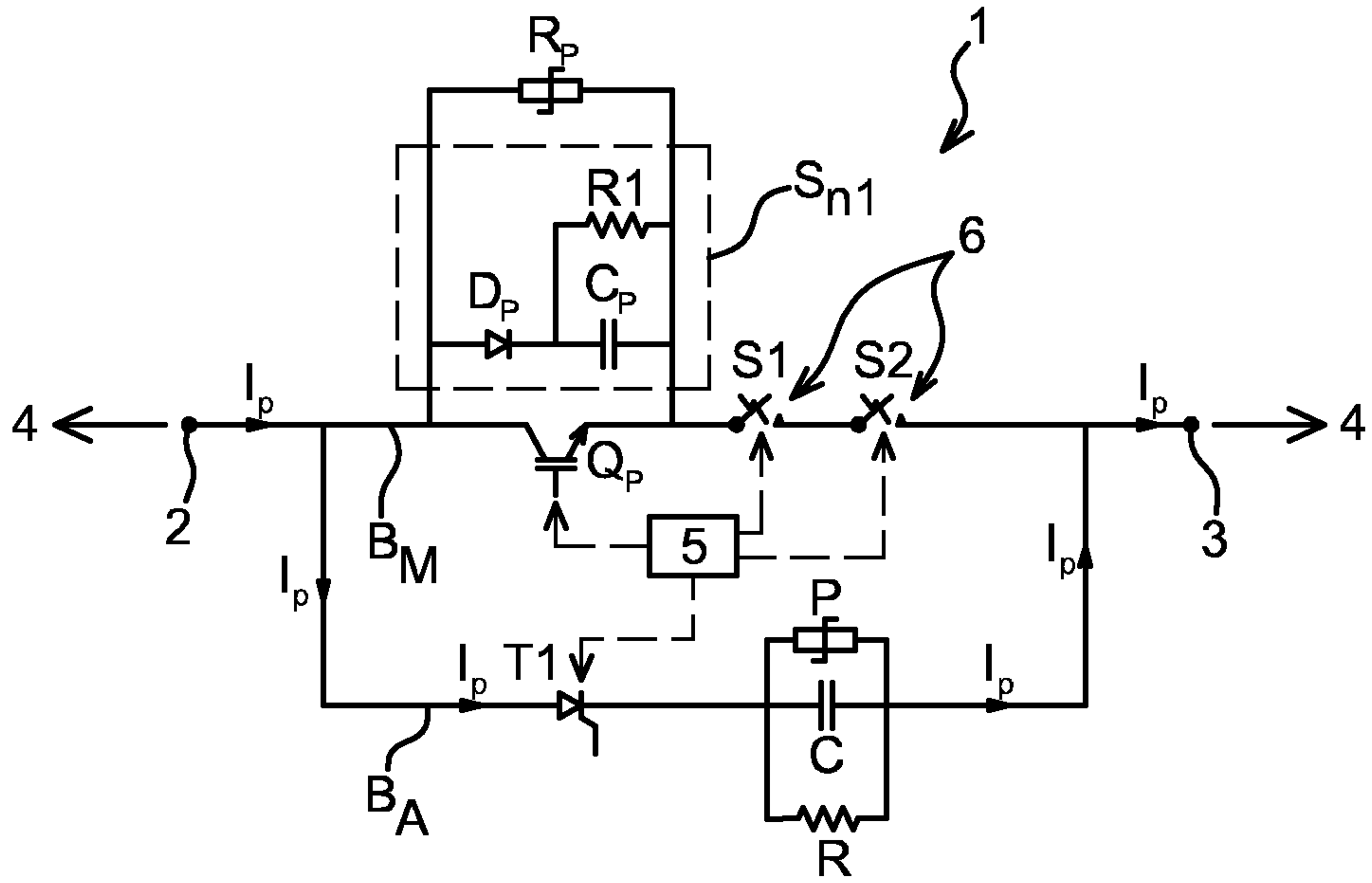

1
R_P
S_{n1}
R1
D_P
C_P
6
S1
S2
4
I_p
I_p
4
Q_P
2
B_M
5
3
I_p
I_p
P
I_p
T1
I_p
C
B_A
R

FIG. 2c

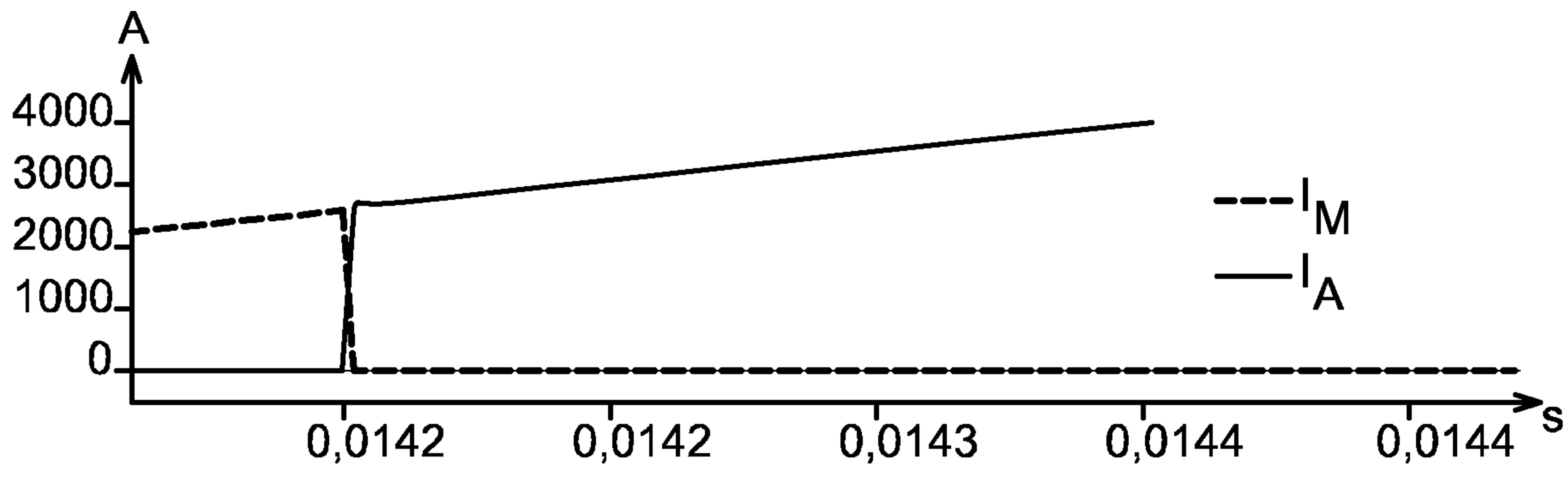
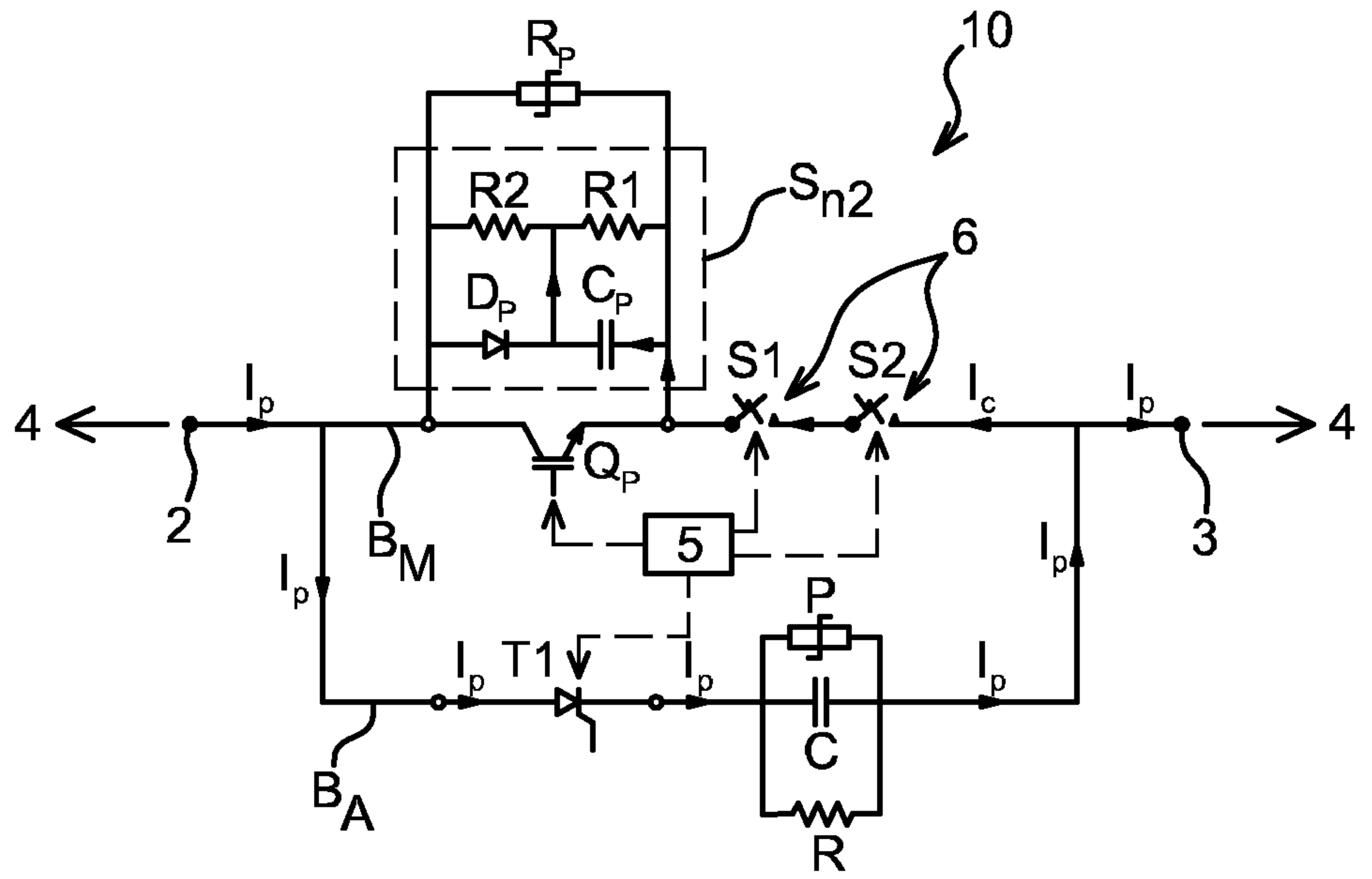

A
4000
3000
2000
1000
0
I_M
I_A
0,0142
0,0142
0,0143
0,0144
0,0144
s

FIG. 2d


10
R_P
R2
R1
S_{n2}
D_P
C_P
6
S1
S2
4
I_p
I_c
I_p
4
Q_P
2
B_M
5
3
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I_p
P
I_p
T1
I_p
I_p
C
B_A
R

FIG. 3a

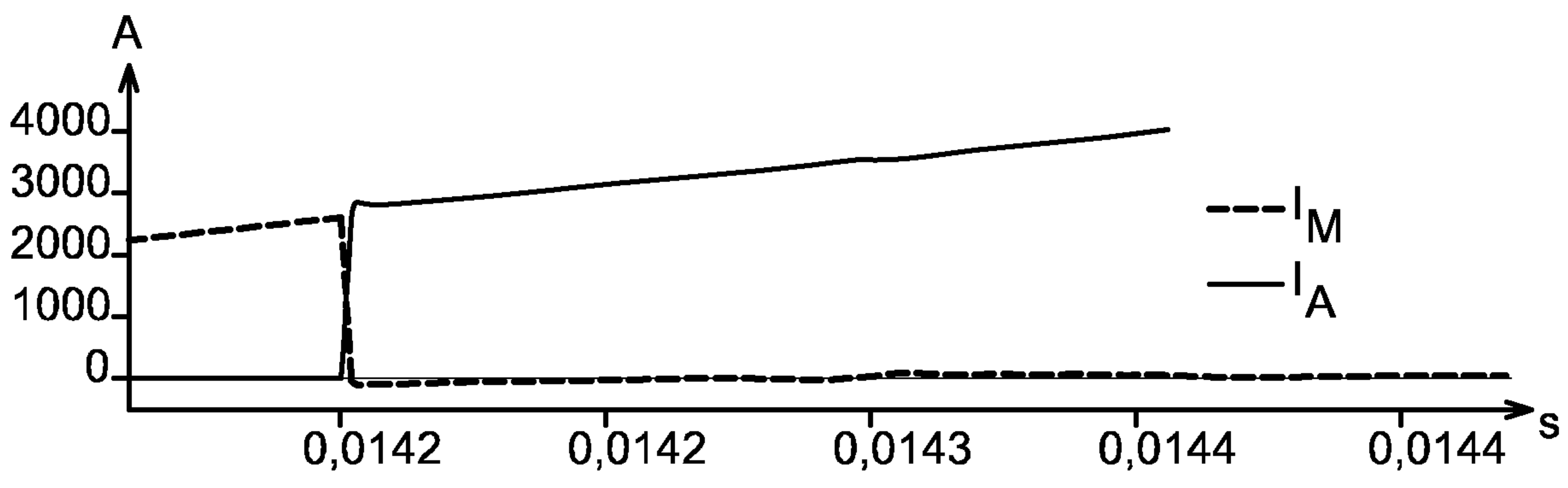
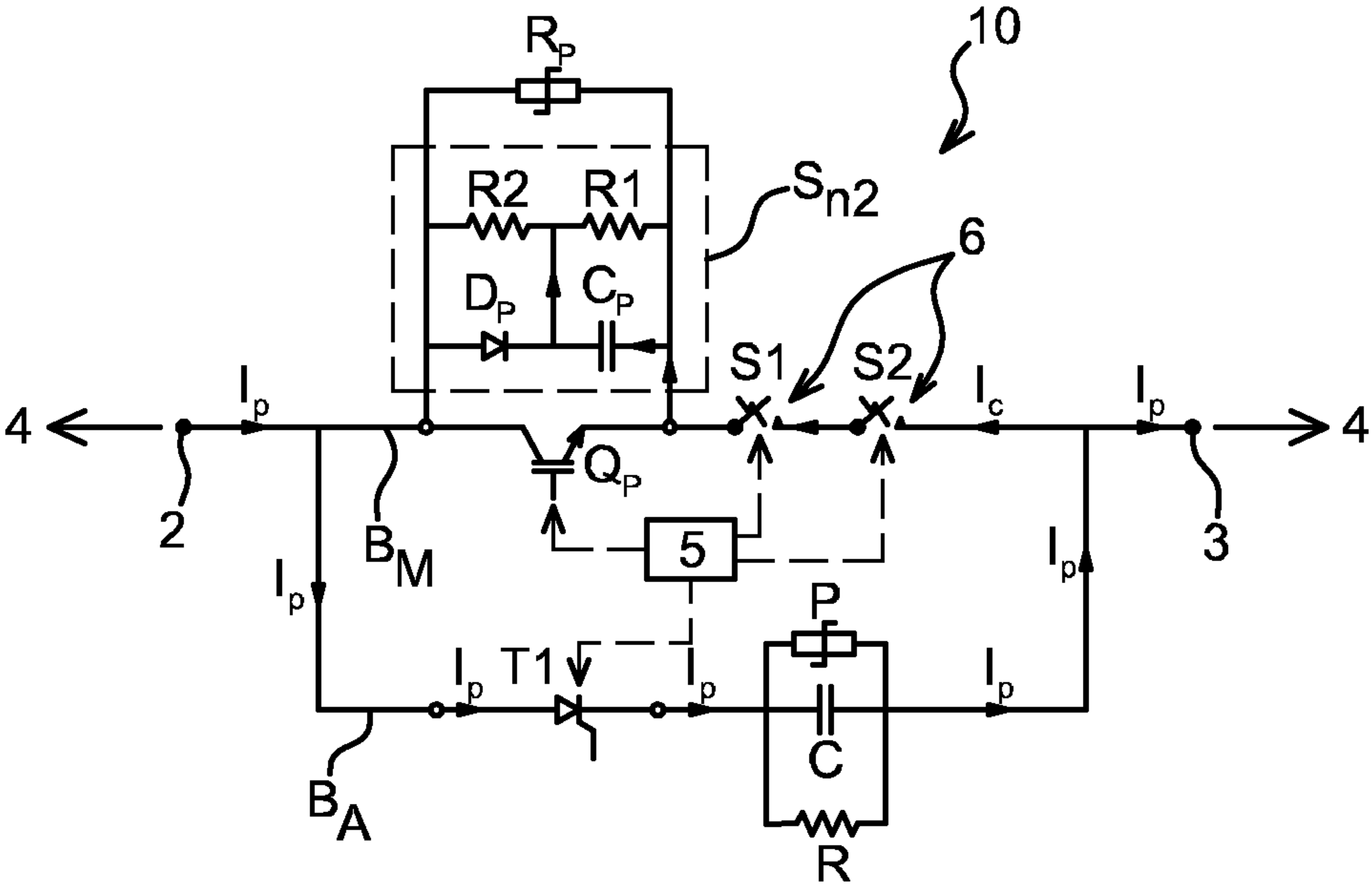

A
4000
3000
2000
1000
0
I_M
I_A
0,0142
0,0142
0,0143
0,0144
0,0144
s

FIG. 3b



10
R_P
S_n2
R2
R1
D_P
C_P
6
S1
S2
4
I_p
I_c
I_p
4
2
B_M
Q_P
3
5
I_p
I_p
P
I_p
T1
I_p
I_p
C
B_A
R

FIG. 3a