

**UNIPOLAR OR BIPOLAR CHOPPING CONVERTER WITH THREE
MAGNETICALLY COUPLED WINDINGS**

DESCRIPTION

TECHNICAL FIELD

The invention relates to a unipolar or
5 bipolar chopping converter, operating in the quadrants
($I_s > 0$; $V_s > 0$) and ($I_s < 0$; $V_s < 0$), and with zero output
current or voltage, having magnetically coupled
windings, which may be configured with the regulation
mode adapted in current source or voltage source. It
10 applies to all types of terrestrial, naval or aerial
equipment using this type of converter, particularly
the electromechanical actuator controls of regulating
automatons for turbine engines.

15 **STATE OF THE PRIOR ART**

The control of electrical actuators with an
RL type load (resistor and inductance in series) may be
achieved either by application of a regulated voltage
at the terminals of the control coil of the actuator,
20 or by a current source, this latter solution often
being preferred in severe environments essentially
because it enables the power used to control the
accessory to be limited.

Chopping current sources may conventionally
25 be grouped together among current sources using the
inductance of the load as energy storage element during
the chopping operation, with as consequence the
application at the terminals of the load, at the

chopping frequency, of an alternatively positive and negative voltage, the transitions between these two states ideally being considered as instantaneous, and current sources supplying a continuous current and, consequently, a continuous voltage at the terminals of the load, in which the energy storage element for the chopping is situated on the control card itself.

Chopping current sources using the inductance of the load as energy storage element have the advantage of having a control that is, at first sight, simple. They comprise few or possibly no inductive elements, which leads to a certain saving in the dimensions of the circuit. On the other hand, they have a certain number of disadvantages. They have a heavy dependency vis-à-vis the value of the inductance of the load: the capability of controlling the instantaneous current in the switches of the current source directly depends on the load inductance value. The resistance to short circuits between the output terminals of the converter or between any output terminal and earth is very difficult. Indeed, in the event of short circuit of the load, it is not possible, except for adding components, to limit the instantaneous current. Consequently, in practice it is necessary to add an inductance at the output of the current source in order to limit the short circuit current, to add a protection and very rapid cut off device to limit the maximum value of the short circuit current, to add a circuit for demagnetising the output inductance to manage the cut off after the detection of the short circuit at the output, to over-dimension the

interfaces (input filtering capacitor) so that they can withstand the short circuit current. Concerning the electromagnetic compatibility aspect (conducted emissions essentially), these current sources are
5 difficult to render compatible with aeronautic emission standards, if a high chopping frequency is desired, especially if the load is controlled at the end of several meters of cable. The result is a chopping frequency reduced typically to below 10 kHz and an
10 obligation to dimension an output filter (shared mode and differential mode) that will play a prominent role in the stability of the assembly. This type of chopping current source is restricted to high power applications, for which a low chopping frequency is not
15 necessarily a handicap.

For current sources supplying a continuous voltage at the terminals of the load, the chopping no longer takes place in the load but the current (or the voltage) is regulated at the output of a chopping
20 converter comprising an inductance storing at least all of the energy transferred to the load and a capacitor is added to smooth out the output voltage. Consequently, the output voltage is virtually continuous at the terminals of the load. There is
25 therefore less difficulty in meeting aeronautic standards for noise emitted in conduction. In the event of short circuit of the load, the current in the converter remains naturally limited. Chopping frequencies exceeding 100 kHz may be envisaged, limited
30 in fact by the efficiency of the converter and the

performance of the gate control circuits of switch elements.

Figure 1a is an electrical diagram of a converter of the prior art supplying a continuous
5 voltage at the terminals of a load. The circuit is supplied by a positive voltage V_p (for example +25V) and a negative voltage V_m (for example -25V) with respect to earth. It comprises two elements T1 and T2 each comprising two windings magnetically coupled
10 around a magnetic core. The windings of a same element T1 or T2 are wound in opposition as indicated by a point in figure 1. The winding E1 of the element T1 has a first end connected to the voltage V_p through the intermediary of a diode D5 inversely mounted in
15 relation to the voltage V_p , its second end being to earth. The winding E2 of the element T1 has a first end connected to a first terminal of a switch Q3 in which the second terminal is connected to the voltage V_p . The second end of the winding E2 is connected to the output
20 terminal S1P of the circuit. The winding E3 of the element T2 has a first end connected to the voltage V_m through the intermediary of a diode D6 inversely mounted in relation to the voltage V_m , its second end being to earth. The winding E4 of the element T2 has a
25 first end connected to a first terminal of a switch Q4 in which the second terminal is connected to the voltage V_m . The second end of the winding E4 is connected to the output terminal S1P of the circuit. A smoothing capacitor C1 is connected between the output
30 S1P and earth.

The converter is transformed into current source by the addition of a means for measuring the output current, and a suitable regulation and modulator. This is shown in figure 1b where the load
5 connected in output of the converter is represented in the form of a resistor R_c and an inductance L_c connected in series. The output current is measured by a measuring means 1 that delivers a representative signal to a first input of a regulation means (or
10 equaliser) 2. A second input E_c of the regulation means 2 receives a set point signal. The output signal of the regulation means 2 is addressed to the input of a modulator 3 that delivers a command signal SQ_3 to the switch Q_3 and a command signal SQ_4 to the switch Q_4 .

15 The converter illustrated in figure 1a comprises therefore four windings and two magnetic cores, which leads to a relatively high cost and a relatively large size of the circuit.

20 DESCRIPTION OF THE INVENTION

In order to reduce the cost and the size of a chopping converter supplying a continuous positive, negative or zero voltage at the terminals of a load, a circuit with three windings coupled to a single
25 magnetic core is proposed, according to the present invention. It is then necessary to add two diodes to the circuit, but these elements are of low cost and of low size.

A first subject of the invention consists
30 in a chopping converter supplied by a positive voltage and a negative voltage with respect to earth, and

delivering an output voltage between a first output terminal and a second output terminal, comprising three windings wound around a magnetic core, a first and a second of said windings being mounted in series and
5 wound in opposition, their common ends, or first ends, being connected to earth, the second end of the first winding being connected to the positive voltage through the intermediary of a first diode inversely mounted in relation to the positive voltage, the second end of the
10 second winding being connected to the negative voltage through the intermediary of a second diode inversely mounted in relation to the negative voltage, the third winding having a first end connected to a mid point of a branch connecting the positive voltage to the
15 negative voltage, the part of branch connecting the mid point to the positive voltage comprising, arranged in series, a first switch forming means and a third diode directly mounted in relation to the positive voltage and together forming a unidirectional switch with
20 direct and inverse blocking capability, the part of branch connecting the mid point to the negative voltage comprising, arranged in series, a second switch forming means and a fourth diode directly mounted in relation to the negative voltage and together forming a
25 unidirectional switch with direct and inverse blocking capability, the second end of the third winding being connected to the output terminal, the third winding having a number of turns greater than the number of turns of the first winding and greater than the number
30 of turns of the second winding.

Advantageously, a smoothing capacitor is connected between the first output terminal and earth.

Also advantageously, in the branch connecting the positive voltage to the negative
5 voltage, said arrangement in series consists in arranging the first and second switch forming means on the side of the respective positive or negative voltages and arranging the diodes on the side of the mid point.

10 The switch forming means may be chosen among MOS transistors, bipolar transistors, IGBT transistors or any other switch having a bi-directional conduction capability and a direct blocking capability.

For a first application, the converter may
15 further comprise a means of measuring the output voltage of the converter, this measuring means delivering an output signal representative of the output voltage to a first input of a regulation means in which a second input receives a set point signal,
20 the regulation means delivering a signal supplied to the input of a modulator in which a first output sends a command signal to the first switch forming means and in which a second output sends a command signal to the second switch forming means, the converter being
25 thereby configured in voltage source.

For a second application, the converter may further comprise a means of measuring the output current of the converter, this measuring means delivering an output signal representative of the
30 output current of the converter to a first input of a regulation means in which a second input receives a set

point signal, the regulation means delivering a signal supplied to the input of a modulator in which a first output sends a command signal to the first switch forming means and in which a second output sends a
5 command signal to the second switch forming means, the converter being thereby configured in current source.

The chopping converter according to the invention may equip an electromechanical actuator control, a regulating automaton, a turbine engine or
10 terrestrial, naval or aeronautic equipment.

The chopping converter according to the present invention may operate according to the following methods.

A first method comprises the following
15 steps, for an operating cycle and to pass a negative current in the load:

- a first step during which a first switch forming means are open, the fourth diode is conducting, the second switch forming means are closed and the
20 first, second and third diodes are blocked during a first part of the cycle, the converter operating in continuous mode or in discontinuous mode,

- a second step, following the first step, during which, the first and second switch forming means
25 are open, the second diode is conducting and the first, third and fourth diodes are blocked during a second part of the cycle, this second part of the cycle not ending the cycle if the converter operates in discontinuous mode and ending the cycle if the
30 converter operates in continuous mode,

- a third step, following the second step if the converter operates in discontinuous mode, during which the first and second switch forming means are open and the first, second, third and fourth diodes are blocked during a third part of the cycle ending at the end of the cycle.

A second method comprises the following steps, for an operating cycle and to pass a positive current in the load:

10 - a first step during which a first switch forming means are closed, the third diode is conducting, the second switch forming means are open and the first, second and fourth diodes are blocked during a first part of the cycle, the converter
15 operating in continuous mode or in discontinuous mode,

 - a second step, following the first step, during which the first diode is conducting, the first and second switch forming means are open and the second, third and fourth diodes are blocked during a
20 second part of the cycle, this second part of the cycle not ending the cycle if the converter operates in discontinuous mode and ending the cycle if the converter operates in continuous mode,

 - a third step, following the second step
25 if the converter operates in discontinuous mode, during which the first and second switch forming means are open, the first, second, third and fourth diodes are blocked, during a third part of the cycle ending at the end of the cycle.

30 A third method comprises the following steps, for an operating cycle and to pass a negative

current in the load, the converter operating in continuous mode:

- 5 - a first step during which a first switch forming means are closed, the third diode is conducting, the second switch forming means are open and the first and fourth diodes are blocked during a first part of the cycle, the second diode being blocked if the output voltage of the converter is, in absolute value, sufficiently low,
- 10 - a second step, following the first step, during which the first diode is conducting, the first and second switch forming means are open and the second, third and fourth diodes are blocked during a second part of the cycle,
- 15 - a third step, following the second step, during which the second switch forming means are closed, the fourth diode is conducting, a first switch forming means are open and the first, second and third diodes are blocked, during a third part of the cycle,
- 20 - a fourth step, following the third step, during which the second diode is conducting, the first and second switch forming means are open and the first, third and fourth diodes are blocked, during a fourth part of the cycle ending at the end of the cycle.
- 25 A fourth method comprises the following steps, for an operating cycle and to pass a positive current in the load, the converter operating in continuous mode:
 - 30 - a first step during which a first switch forming means are closed, the third diode is conducting, the second switch forming means are open

and the first, second and fourth diodes are blocked during a first part of the cycle,

- a second step, following the first step, during which the first diode is conducting, the first
5 and second switch forming means are open and the second, third and fourth diodes are blocked during a second part of the cycle,

- a third step, following the second step, during which the second switch forming means are
10 closed, the fourth diode is conducting, a first switch forming means are open and the second and third diodes are blocked, during a third part of the cycle, the first diode is blocked if the output voltage is, in absolute value, sufficiently low,

- a fourth step, following the third step, during which the second diode is conducting, the first
15 and second switch forming means are open and the first, third and fourth diodes are blocked, during a fourth part of the cycle ending at the end of the cycle.

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BRIEF DESCRIPTION OF DRAWINGS

The present invention may best be understood and other advantages and particularities will become apparent by reference to the following
25 description, provided as an indication only and in no way limiting and by referring to the accompanying drawings in which:

- figure 1a is an electrical diagram of a chopping converter of the prior art supplying a
30 continuous voltage at the terminals of a load,

- figure 1b is an electrical diagram of the converter of figure 1a used as chopping current source by addition of a means of measuring the output current, as well as suitable equaliser and modulator,

5 - figure 2 is an electrical diagram of a chopping converter supplying a continuous voltage at the terminals of a load, according to the invention,

- figures 3A to 3N illustrate the operating mode of the present invention,

10 - figures 4A to 4F are chronograms corresponding to different operating modes illustrated by figures 3A to 3N,

- figure 5a shows the principle of using the converter according to the invention as voltage
15 source,

- figure 5b shows the principle of using the converter according to the invention as current source.

20 **DETAILED DESCRIPTION OF AN EMBODIMENT OF THE INVENTION**

Figure 2 is an electrical diagram of a chopping converter supplying a continuous voltage at the terminals of a load, according to the invention. This converter may be, in the same way as for the
25 converter described in figures 1a and 1b, converted into chopping current source by the addition of a means (direct or indirect) of measuring the current of the load and suitable equaliser and modulator. As in figure 1a, the circuit is supplied by a positive voltage V_p
30 (for example +25V) and a negative voltage V_m (for example -25V) with respect to earth. It comprises a

transformer forming element and comprising three windings L_p , L_{s1} and L_{s2} wound around a unique magnetic core. The direction of the winding is indicated by a point in figure 2. The windings L_{s1} and L_{s2} are mounted
5 in series to constitute the secondary of the transformer forming element, their shared point (their first ends) being to earth. The winding L_p constitutes the primary of the transformer forming element. The second end of the winding L_{s1} is connected to the
10 voltage V_p through the intermediary of a diode $D1$ inversely mounted in relation to the voltage V_p . The second end of the winding L_{s2} is connected to the voltage V_m through the intermediary of a diode $D2$ inversely mounted in relation to the voltage V_m . The
15 winding L_p has a first end connected to the cathode of a diode $D3$ and to the anode of a diode $D4$. The second end of the winding L_p is connected to the output terminal SP of the circuit. A first terminal of a switch $Q1$ is connected to the anode of the diode $D3$ and
20 its second terminal is connected to the voltage V_p . A first terminal of a switch $Q2$ is connected to the cathode of the diode $D4$ and its second terminal is connected to the voltage V_m . A smoothing capacitor C_s is connected between the output SP and earth. The
25 output SM may be connected to mechanical earth directly, or via a resistor, depending on the needs of the user.

The switches $Q1$ and $Q2$ are advantageously N-channel or P-channel MOSFET transistor elements,
30 depending on the needs of the user. They may be

replaced by any other switch having a bi-directional conduction capability and a direct blocking capability.

N_p being the number of turns of the winding L_p , N_{s1} being the number of turns of the winding L_{s1} and N_{s2} being the number of turns of the winding L_{s2} , N_p is greater than N_{s1} and N_{s2} , for example $N_{s1} = N_{s2} = 0.75 N_p$.

Figure 2 mentions the following voltages:

- v_{q1} at the terminals of Q_1 ,
- v_{q2} at the terminals of Q_2 ,
- v_{d1} at the terminals of D_1 ,
- v_{d2} at the terminals of D_2 ,
- v_{d3} at the terminals of D_3 ,
- v_{d4} at the terminals of D_4 ,
- v_{ls1} at the terminals of L_{s1} ,
- v_{ls2} at the terminals of L_{s2} ,
- v_{lp} at the terminals of L_p , and
- v_s at the terminals of C_s , i.e. the output voltage of the converter.

Figure 2 also mentions the following currents:

- i_{ls1} flowing through the winding L_{s1} ,
- i_{ls2} flowing through the winding L_{s2} ,
- i_{lp} flowing through the winding L_p , and
- i_s flowing through the load Z of the converter, i.e. the output current.

The operation of the chopping converter will now be explained in reference to figures 3A to 3N as a function of the commands (closing, opening) sent to the switches Q_1 and Q_2 . In these figures, the currents that flow in the circuit are indicated by bold

lines. As will be seen, the converter according to the invention is a two quadrant converter:

$v_s > 0$, $i_s > 0$ and $v_s < 0$, $i_s < 0$.

Figures 3A to 3F concern an operating mode
 5 where a single transistor Q1 or Q2 (forming switch) conducts when the output current is negative ($i_s < 0$) or when the output current is positive ($i_s > 0$).

Figures 3A to 3C concern an operating mode
 where the output current "is" is negative, for an
 10 operating cycle (from $t=0$ to $t=T$).

Figure 3A illustrates a first step of the operating cycle between the instants $t=0$ and $t=t_1$ (where $t_1 < T$). The circuit can operate in continuous mode and in discontinuous mode. During this step, the
 15 command of the circuit is such that:

- Q2 and D4 conduct,
- Q1, D1, D2 and D3 are blocked.

Figure 3B illustrates a second step of the operating cycle, between the instants $t=t_1$ and $t=t_2$. The
 20 circuit may operate in continuous mode (in this case $t_2=T$) or in discontinuous mode. During this step, the command of the circuit is such that:

- D2 conducts,
- Q1, Q2, D1, D3 and D4 are blocked.

Figure 3C illustrates a third step of the operating cycle, uniquely for the discontinuous mode, between $t=t_2$ and $t=T$. During this step, the command of the circuit is such that:

- Q1, Q2, D1, D2, D3 and D4 are blocked,

- the current "is" circulating in the load is supplied by the energy accumulated in the capacitor C_s .

Figure 4A shows the chronograms corresponding to the operating mode illustrated by figures 3A to 3C for a discontinuous mode, therefore for an operating cycle comprising three steps.

Figure 4B shows the chronograms corresponding to the operating mode illustrated by figures 3A to 3C for a continuous mode, therefore an operating cycle comprising two steps.

Figures 3D to 3F concern an operating mode where the output current "is" is positive, for an operating cycle (from $t=0$ to $t=T$).

Figure 3D illustrates a first step of the operating cycle between the instants $t=0$ and $t=t_1$ (where $t_1 < T$). The circuit may operate in continuous mode and in discontinuous mode. During this step, the command of the circuit is such that:

- Q1 and D3 conduct,
- Q2, D1, D2 and D4 are blocked.

Figure 3E illustrates a second step of the operating cycle, between the instants $t=t_1$ and $t=t_2$. The circuit may operate in continuous mode (in this case $t_2=T$) or in discontinuous mode. During this step, the command of the circuit is such that:

- D1 conducts,
- Q1, Q2, D2, D3 and D4 are blocked.

Figure 3F illustrates a third step of the operating cycle, uniquely for the discontinuous mode,

between $t=t_2$ and $t=T$. During this step, the control of the circuit is such that:

- Q1, Q2, D1, D2, D3 and D4 are blocked,
 - the current "is" flowing in the load is
- 5 supplied by the energy accumulated in the capacitor Cs.

Figure 4C shows the chronograms corresponding to the operating mode illustrated by figures 3D to 3F for a discontinuous mode, therefore for an operating cycle comprising three steps.

10 Figure 4D shows the chronograms corresponding to the operating mode illustrated by figures 3D to 3F for a continuous mode, therefore for an operating cycle comprising two steps.

Figures 3G to 3N concern an operating mode
 15 where the two transistors Q1 and Q2 (forming switch) conduct when the output current is negative ($i_s < 0$) and when the output current is positive ($i_s > 0$). The operation described is in continuous mode.

Figures 3G to 3J concern an operating mode
 20 where the output current "is" is negative, for an operating cycle (from $t=0$ to $t=T$).

Figure 3G illustrates a first step of the operating cycle, between the instants $t=0$ and $t=t_1$. During this step, the command of the circuit is such
 25 that:

- Q1 and D3 conduct,
- Q2, D1 and D4 are blocked,
- D2 is blocked if the continuous output voltage is, in absolute value, sufficiently low.

30 Figure 3H illustrates a second step of the operating cycle, between the instants $t=t_1$ and $t=t_2$.

During this step, the command of the circuit is such that:

- D1 conducts,
- Q1, Q2, D2, D3 and D4 are blocked.

5 Figure 3I illustrates a third step of the operating cycle, between the instants $t=t_2$ and $t=t_3$. During this step, the command of the circuit is such that:

- Q2 and D4 conduct,
- 10 - Q1, D1, D2 and D3 are blocked

Figure 3J illustrates a fourth step of the operating cycle, between the instants $t=t_3$ and $t=T$. During this step, the command of the circuit is such that:

- 15 - D2 conducts,
- Q1, Q2, D1, D3 and D4 are blocked.

Figures 3K to 3N concern an operating mode where the output current "is" is positive, for an operating cycle (from $t=0$ to $t=T$).

20 Figure 3K illustrates a first step of the operating cycle, between the instants $t=0$ and $t=t_1$. During this step, the command of the circuit is such that:

- Q1 and D3 conduct,
- 25 - Q2, D1, D2 and D4 are blocked.

Figure 3L illustrates a second step of the operating cycle, between the instants $t=t_1$ and $t=t_2$. During this step, the command of the circuit is such that:

- 30 - D1 conducts,
- Q1, Q2, D2, D3 and D4 are blocked.

Figure 3M illustrates a third step of the operating cycle, between the instants $t=t_2$ and $t=t_3$. During this step, the command of the circuit is such that:

- 5 - Q2 and D4 conduct
- Q1, D2 and D3 are blocked,
- D1 is blocked if the continuous output voltage is, in absolute value, sufficiently low.

Figure 3N illustrates a fourth step of the operating cycle, between the instants $t=t_3$ and $t=T$. During this step, the command of the circuit is such that:

- D2 conducts,
 - Q1, Q2, D1, D3 and D4 are blocked.
- 15 Figure 4E shows the chronograms corresponding to the operating mode illustrated by figures 3G to 3J, therefore for an operating cycle comprising four steps.

Figure 4F shows the chronograms corresponding to the operating mode illustrated by figures 3K to 3N, therefore for an operating cycle also comprising four steps.

Figure 5a shows the principle of using the converter according to the invention as voltage source by the addition of means 11 of measuring the differential voltage between the outputs SP and SM, a suitable equaliser 12 receiving a set point E_c and a suitable modulator 13. The outputs of the modulator 13 supply the command voltages SQ1 and SQ2 of the transistors Q1 and Q2.

Figure 5b shows the principle of using the converter according to the invention as current source by the addition of means 21 of measuring "is" output currents of the converter, a suitable equaliser 22 receiving a set point E_c and a suitable modulator 23. The outputs of the modulator 23 supply the command voltages SQ_1 and SQ_2 of the transistors Q_1 and Q_2 .

CLAIMS

1. Chopping converter supplied by a positive voltage (V_p) and a negative voltage (V_m) with respect to earth, and delivering an output voltage between a first output terminal (SP) and a second output terminal (SM), the latter terminal being directly connected to earth or through a resistor, comprising three windings (L_{s1} , L_{s2} , L_p) wound around a magnetic core, a first (L_{s1}) and a second (L_{s2}) of said windings being mounted in series and wound in opposition, their shared ends, or firsts ends, being connected to earth, the second end of the first winding (L_{s1}) being connected to the positive voltage (V_p) through the intermediary of a first diode ($D1$) inversely mounted in relation to the positive voltage (V_p), the second end of the second winding (L_{s2}) being connected to the negative voltage (V_m) through the intermediary of a second diode ($D2$) inversely mounted in relation to the negative voltage (V_m), the third winding (L_p) having a first end connected to a mid point of a branch connecting the positive voltage (V_p) to the negative voltage (V_m), the part of branch connecting the mid point to the positive voltage (V_p) comprising, arranged in series, a first switch forming means ($Q1$) and a third diode ($D3$) directly mounted in relation to the positive voltage (V_p), and together forming a unidirectional switch with direct and inverse blocking capability, the part of the branch connecting the mid point to the negative voltage (V_m) comprising, arranged in series, a second switch forming means ($Q2$)

and a fourth diode (D4) directly mounted in relation to the negative voltage (V_m), and together forming a unidirectional switch with direct and inverse blocking capability, the second end of the third winding (L_p) being connected to the first output terminal (SP), the third winding (L_p) having a number of turns greater than the number of turns of the first winding (L_{s1}) and greater than the number of turns of the second winding (L_{s2}).

10

2. Chopping converter according to claim 1, in which a smoothing capacitor (C_s) is connected between the first output terminal (SP) and earth.

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3. Chopping converter according to one of claims 1 or 2, in which, in the branch connecting the positive voltage (V_p) to the negative voltage (V_m), said arrangement in series consists in arranging the first (Q1) and second (Q2) switch forming means on the side of the respective positive or negative voltages and arranging the diodes (D3, D4) on the side of the mid point.

20

4. Chopping converter according to any of claims 1 to 3, in which the first (Q1) and second (Q2) switch forming means are chosen among MOS transistors, bipolar transistors, IGBT transistors or any other switch having a bi-directional conduction capability and a direct blocking capability.

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5. Chopping converter according to any of claims 1 to 4, further comprising a means (11) of measuring the output voltage of the converter, this measuring means delivering an output signal
5 representative of the output voltage to a first input of a regulation means (12) in which a second input receives a set point signal, the regulation means (12) delivering a signal supplied to the input of a modulator (13) in which a first output sends a command
10 signal (SQ1) to the first switch forming means (Q1) and in which a second output sends a command signal (SQ2) to the second switch forming means (Q2), the converter being thereby configured in voltage source.

15 6. Chopping converter according to any of claims 1 to 4, further comprising a means (21) of measuring the output current (is) of the converter, this measuring means delivering an output signal representative of the output current of the converter
20 to a first input of a regulation means (22) in which a second input receives a set point signal, the regulation means (22) delivering a signal supplied to the input of a modulator (23) in which a first output sends a command signal (SQ1) to the first switch
25 forming means (Q1) and in which a second output sends a command signal (SQ2) to the second switch forming means (Q2), the converter being configured in current source.

7. Electromagnetic actuator control
30 comprising a chopping converter according to any of claims 1 to 6.

8. Regulating automaton comprising a chopping converter according to any of claims 1 to 6.

5 9. Terrestrial, naval or aeronautic equipment comprising a chopping converter according to any of claims 1 to 6.

10 10. Turbine engine comprising a chopping converter according to any of claims 1 to 6.

15 11. Method for operating a chopping converter according to any of claims 1 to 6, the converter being supplied by a positive voltage (V_p) and a negative voltage (V_m) with respect to earth, the converter delivering an output current (i_s) in a load (Z) connected between the first output terminal (SP) and the second output terminal (SM), said terminal being connected directly or through a resistor to earth, characterised in that it comprises the following steps, for an operating cycle and to pass a negative current in the load (Z):

25 - a first step during which a first switch forming means (Q1) are open, the fourth diode (D4) is conducting, the second switch forming means (Q2) are closed and the first (D1), second (D2) and third (D3) diodes are blocked during a first part of the cycle, the converter operating in continuous mode or in discontinuous mode,

30 - a second step, following the first step, during which, the first (Q1) and second (Q2) switch

forming means are open, the second diode (D2) is conducting and the first (D1), third (D3) and fourth (D4) diodes are blocked during a second part of the cycle, this second part of the cycle not ending the cycle if the converter operates in discontinuous mode and ending the cycle if the converter operates in continuous mode,

- a third step, following the second step if the converter operates in discontinuous mode, during which the first (Q1) and second (Q2) switch forming means are open and the first (D1), second (D2), third (D3) and fourth (D4) diodes are blocked during a third part of the cycle ending at the end of the cycle.

12. Method for operating a chopping converter according to any of claims 1 to 6, the converter being supplied by a positive voltage (V_p) and a negative voltage (V_m) with respect to earth, the converter delivering an output current (i_s) in a load (Z) connected between the first output terminal (SP) and the second output terminal (SM), characterised in that it comprises the following steps, for an operating cycle and to pass a positive current in the load (Z):

- a first step during which a first switch forming means (Q1) are closed, the third diode (D3) is conducting, the second switch forming means (Q2) are open and the first (D1), second (D2) and fourth (D4) diodes are blocked during a first part of the cycle, the converter operating in continuous mode or in discontinuous mode,

- a second step, following the first step, during which the first diode (D1) is conducting, the first (Q1) and second (Q2) switch forming means are open and the second (D2), third (D3) and fourth (D4) diodes are blocked during a second part of the cycle, this second part of the cycle not ending the cycle if the converter operates in discontinuous mode and ending the cycle if the converter operates in continuous mode,
- a third step, following the second step if the converter operates in discontinuous mode, during which the first (Q1) and second (Q2) switch forming means are open, the first (D1), second (D2), third (D3) and fourth (D4) diodes are blocked, during a third part of the cycle ending at the end of the cycle.

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13. Method for operating a chopping converter according to any of claims 1 to 6, the converter being supplied by a positive voltage (V_p) and a negative voltage (V_m) with respect to earth, the converter delivering an output current (i_s) in a load (Z) connected between the first output terminal (SP) and the second output terminal (SM), characterised in that it comprises the following steps, for an operating cycle and to pass a negative current in the load (Z), the converter operating in continuous mode:

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- a first step during which a first switch forming means (Q1) are closed, the third diode (D3) is conducting, the second switch forming means (Q2) are open and the first (D1) and fourth (D4) diodes are blocked during a first part of the cycle, the second

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diode (D2) being blocked if the output voltage of the converter is, in absolute value, sufficiently low,

- a second step, following the first step, during which the first diode (D1) is conducting, the first (Q1) and second (Q2) switch forming means are open and the second (D2), third (D3) and fourth (D4) diodes are blocked during a second part of the cycle,

- a third step, following the second step, during which the second switch forming means (Q2) are closed, the fourth diode (D4) is conducting, a first switch forming means (Q1) are open and the first (D1), second (D2) and third (D3) diodes are blocked, during a third part of the cycle,

- a fourth step, following the third step, during which the second diode (D2) is conducting, the first (Q1) and second (Q2) switch forming means are open and the first (D1), third (D3) and fourth (D4) diodes are blocked, during a fourth part of the cycle ending at the end of the cycle.

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14. Method for operating a chopping converter according to any of claims 1 to 6, the converter being supplied by a positive voltage (V_p) and a negative voltage (V_m) with respect to earth, the converter delivering an output current (i_s) in a load (Z) connected between the first output terminal (SP) and the second output terminal (SM), characterised in that it comprises the following steps, for an operating cycle and to pass a positive current in the load (Z), the converter operating in continuous mode:

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- a first step during which a first switch forming means (Q1) are closed, the third diode (D3) is conducting, the second switch forming means (Q2) are open and the first (D1), second (D2) and fourth (D4) diodes are blocked during a first part of the cycle,
- a second step, following the first step, during which the first diode (D1) is conducting, the first (Q1) and second (Q2) switch forming means are open and the second (D2), third (D3) and fourth (D4) diodes are blocked during a second part of the cycle,
- a third step, following the second step, during which the second switch forming means (Q2) are closed, the fourth diode (D4) is conducting, a first switch forming means (Q1) are open and the second (D2) and third (D3) diodes are blocked, during a third part of the cycle, the first diode (D1) is blocked if the output voltage is, in absolute value, sufficiently low,
- a fourth step, following the third step, during which the second diode (D2) is conducting, the first (Q1) and second (Q2) switch forming means are open and the first (D1), third (D3) and fourth (D4) diodes are blocked, during a fourth part of the cycle ending at the end of the cycle.