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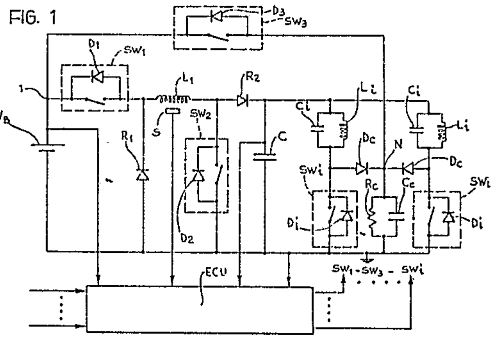
(54) A circuit for the piloting of inductive loads, particularly for operating the electro-injectors of a diesel-cycle internal combustion engine.

(57) The circuit comprises:
- an input (1) for connection to a low-tension supply (V_S),
- a storage coil (L_1) for storing energy delivered by the supply (V_B), and
- electronic switching devices (SW_1, SW_2, SW_i) for controlling the connection between the input (1), the storage coil (L_1) and each of the loads (L_i) in a predetermined manner to achieve a rapid transfer of current to each of the loads selectively,
- a capacitor (C) situated in parallel with the branch circuits containing the loads (L_1) and connected to the coil (L_1) and the electronic switching devices (SW_1, SW_2, SW_i), and
- an electronic control unit (ECU) for piloting the electronic switching devices (SW_1, SW_2, SW_i) according to a first operative mode in which, to transfer current to one of the loads (L_i), the switching devices cause in succession, after the connection of the storage coil (L_1) to the supply (V_B):
the connection of the storage coil (L_1) to the capacitor (C) so as to form a resonant circuit, and then
the discharge of the resonant circuit (L_1, C) into the load (L_i).

FIG. 1



EP 0 305 344 A1

Description

A circuit for the piloting of inductive loads, particularly for operating the electro-injectors of a diesel-cycle internal combustion engine

The present invention relates to a circuit for the piloting of inductive loads, and particularly for the control of the electro-injectors of a diesel-cycle internal combustion engine.

More specifically, the subject of the invention is a circuit comprising:

an input for connection to a low-tension supply,

a storage coil for storing energy delivered by the supply, and

electronic switching means for controlling the connection between the input, the storage coil and the loads in a predetermined manner to achieve a rapid transfer of current to each of the loads selectively.

A circuit of this type is described in Italian patent application No. 67953-A/85. This known circuit comprises a plurality of branch circuits, in each of which a capacitor is connected in parallel with an inductive load and forms a resonant circuit with the load. The rapid transfer of current to each of the loads is achieved by first storing energy delivered by the supply to the storage coil and then connecting the storage coil to the resonant circuit including the load to be activated.

Solenoids for operating the electro-injectors for diesel engines represent non-linear inductive loads of relatively small inductance. Consequently, with the known circuit described above, it is only possible to transfer sufficient energy to such loads if capacitors of good quality and high capacitance, which are therefore bulky and expensive, are used in parallel with the loads.

An object of the present invention is to produce a circuit for controlling inductive loads of the type defined above, which enables a large amount of energy to be transferred rapidly to the load selected from time to time, without requiring the use of a plurality of large and expensive capacitors.

According to the invention, this object is achieved by means of a circuit of the type specified above, whose main characteristic lies in the fact that it also includes:

a capacitor arranged in parallel with the branch circuits containing the loads, and connected to the storage coil and the electronic switching means, and an electronic control unit for piloting the electronic switching means in a first operative mode in which, to transfer current to one of the loads, the switching means, after having connected the storage coil to the supply, connect the coil to the capacitor so as to form a resonant circuit and then discharge the resonant circuit into the load.

In the circuit according to the invention, as in the known circuit, a capacitor may be connected in parallel with each load to enable the current to be cancelled out rapidly when the load is deactivated. In the prior-art circuit described above, this capacitor is represented by the same large-capacitance capacitor used for the transfer of current to the load. In the circuit according to the invention, any quenching capacitor connected in parallel with each load has a much smaller capacitance than that of the capacitor used for transferring current to the load selected from time to time.

When the circuit according to the invention is used for piloting the injectors of a diesel engine, the supply is typically constituted by the battery of the motor vehicle. In some circumstances, this battery is unable to deliver a sufficiently high current for the piloting circuit to be able to energise the electro-injectors in the desired manner. This may occur, for example, when the battery is not sufficiently charged or when, for various reasons, the impedance "felt" by the battery is unusually high. In such a situation, the prior-art circuit described above is unable to pilot the electro-injectors in a satisfactory manner.

A further object of the present invention is to produce a circuit of the type specified above which is able to ensure the correct functioning of the electro-injectors even when the supply is unable to deliver a current of sufficiently high intensity.

This object is achieved according to the invention by means of a circuit of the type specified above, characterised in that it also includes sensor means for supplying electrical signals indicative of the current delivered by the supply, and in that the electronic control unit is connected to the sensor means and is arranged to pilot the electronic switching means in the first operative mode and in a second operative mode when the current delivered by the supply is greater than and less than a predetermined level, respectively, the control unit being able, in the second operative mode, to cause the connection of the capacitor to the supply through voltage-boosting means, so as to charge the capacitor to a predetermined voltage level which is greater than the supply voltage, and then

the discharge of the energy stored in the capacitor to the load selected from time to time.

Further characteristics and advantages of the present invention will become clear from the detailed description which follows with reference to the appended drawings,provided by way of non-limiting example, in which:

Figure 1 is an electrical diagram of a circuit according to the invention, and

Figure 2 is a graph which shows the ideal trace of the excitation current of the solenoid for operating an electro-injector for diesel engines as a function of time, and

Figures 3 to 5 are three sets of graphs which illustrate states of the devices of the circuit according to the invention and signals developed in the circuit in three different operating conditions.

With reference to Figure 1, a circuit according to the invention for the piloting of a plurality of inductive loads L_i comprises an input terminal 1 connected in use to a low-tension, direct-voltage supply V_B, such as a battery. In particular, the inductive loads L_i may represent the solenoids for operating the electro-injectors of a diesel engine for a motor vehicle. In this case, the supply V_B is constituted by the battery of the motor vehicle.

A storage coil, indicated L_1, can be connected to the input terminal 1 through a controlled electronic switch, generally indicated SW_1, which is open at rest. The switch SW_1 has been shown as an interrupter with which a diode D_1 is connected in parallel. This switch may be be constituted, for example, by an integrated MOSFET-type transistor, and in that case the diode D_1 is constituted by its parasitic diode.

A diode whose anode is connected to earth and whose cathode is connected between the storage coil L_1 and the controlled switch SW_1 is indicated R_1.

A further controlled switch SW_2, similar to SW_1 is connected between L_1 and earth in the manner illustrated.

L_1 is connected to a first terminal of a capacitor C whose other terminal is connected to earth. A plurality of branch circuits is connected in parallel with C and each includes an inductive load L_i in series with which a controlled electronic switch SW_i of a similar type to SW_1 and SW_2 is connected. A respective capacitor C_i may be connected in parallel with each load L_i for quenching it, that is, for rapidly cancelling out the current in the corresponding load L_i when the latter is deactivated.

A resistor and a capacitor, indicated R_c and C_c, are connected in parallel with each other between the earth and a junction N to which are connected the cathodes of diodes D_c, each of which has its anode connected between a load L_i and the associated controlled switch SW_i. The diodes D_c together form an OR-type circuit.

A further controlled switch SW_4, similar to the above, is connected between the junction N and the input 1.

An electronic control unit produced in known manner is indicated ECU and comprises, for example, a microprocessor unit and input/output interface circuits. The unit ECU has a series of inputs connected to the earth of the circuit described above, to the positive pole of the supply V_B, and to a sensor S which is adapted to provide electrical signals indicative of the current flowing in the storage coil L_1 during operation. The sensor S may be constituted, for example, by a Hall-effect sensor. As an alternative to this solution, the non-earth terminal of the capacitor C may be connected to the unit ECU for detecting the current flowing in L_1: the voltage established across the terminals of C at particular stages of operation is related to the intensity of the current flowing in L_1.

A further alternative solution for the detection of the current flowing in L_1 could be constituted, for example, by a shunt resistor connected in series with L_1 and connected to the ECU.

The unit ECU has a plurality of outputs connected in order to the control inputs of the switches SW_1, SW_2, SW_3 and SW_i.

In order to pilot the electro-injectors of a diesel engine, the unit ECU may be provided with further electrical input signals, such as, for example, the rate of revolution of the engine, etc.

Before describing the operation of the circuit shown in Figure 1, some considerations concerning the ideal trace of the current I_{Li} in the solenoid for operating an electro-injector for a diesel engine will be put forward. This ideal behaviour is shown in Figure 2 as a function of time t. The ideal curve illustrated has a rising slope $\underline{a}$ followed by a stage $\underline{b}$ of substantially constant high-current intensity I_{max}, followed by a transition $\underline{c}$ towards a holding current level I_h. This current is maintained for a certain period of time (section $\underline{d}$ of the curve) and is then followed by the "quenching" of the current (stage $\underline{e}$) with possible inversion and definitive cancelling out of the current (stage $\underline{f}$).

For optimal and exact control of the injection it is necessary that the actuation time of individual injectors be precisely controllable. For this purpose, therefore, it is necessary that the times during which the current rises and subsequently falls are extremely short, and less than the minimum injection time by at least one order of magnitude.

With reference to Figures 1, 3 and 4, we shall now see how the circuit according to the invention is able to make the current rise rapidly in a particular load each time that load is to be activated.

Figure 3 shows the states of SW_1, SW_2 and of the switch SW_i associated with the load L_i to be energised, and the traces of the current I_{L1} in the storage coil, of the voltage V_C across the capacitor C and of the current I_{Li} in the load.

In order to make a current pass into the load L_i, the unit ECU causes the switches SW_1 and SW_2 to close at a time t_O. All the other switches remain open. In this condition, an increasing current flows in the storage coil L_1, as shown in Figure 3.

At a subsequent time t_1, SW_1 and SW_2 are opened, whilst the switch SW_i associated with the load to be energised is closed. In this condition, the storage inductor L_1 is disconnected from the supply but is connected to the capacitor C with which it forms a resonant circuit. This resonant circuit is discharged to the load L_i associated with the switch SW_i which is closed. The current I_{Li} decays in the manner illustrated, whilst the voltage across the capacitor C(i) increases and then decreases until it reaches zero at a time t_2. The current in the selected load therefore increases from the time t_1 until it reaches a maximum value at the time t_2, and then starts to decay, as shown in Figure 3. In order to extend the period for which the current persists at high-intensity levels in the load, the unit ECU may be arranged to cause successive openings and closings of SW_1 after the time t_2, with resultant "chopping" of the current I_{Li}, as shown by the broken line in Figure 3.

The rapid transfer of energy from the supply to the generic load L_i by means of storage in L_1 and the consequent discharge of the resonant circuit $L_{1\text{-}C}$ can be achieved, provided that the supply V_B is able to deliver a current of sufficient intensity.

According to the invention, the control unit ECU may be arranged to detect the intensity of the current which can be delivered by the supply. This may be achieved by the acquisition of the signals provided by the sensor S, or by the reading of the voltage across C when SW_1 and SW_2 are open, or even by the reading of the voltage across a shunt resistor arranged in series with the storage coil L_1. When the current delivered by the supply is less than a predetermined value, the unit ECU can also determine (and possibly signal for diagnostic purposes) whether the inadequacy of the current is due to a low charge level of the supply or to an anomaly in the circuitry connected to the supply, by reading the voltage V_B of the supply.

In any case, when the unit ECU detects that the current which can be delivered by the supply is less than a predetermined threshold, it puts into operation a second procedure for the transfer of current to the load L_i selected from time to time. In this procedure, which will now be described with reference to Figures 1 and 4, the unit ECU causes successive simultaneous closures of SW_1 and SW_2, as indicated at the times t_0, t_2 and t_4 in Figure 4. The switches SW_3 and SW_i, however, are kept open.

Upon each closure of SW_1 and SW_2, the current in the storage coil L_i increases until, as at the times t_1, t_3 and t_5, the switches are opened. Upon each opening of SW_1 and SW_2, the voltage across the capacitor C is increased. The diode R_2 prevents the discharge of C during the stage of storage in L_1. The diode P_2 also serves to protect SW_2 when the capacitor C is subsequently discharged.

The voltage across C therefore rises in steps and can be brought to a level greater than that of the supply, until a level V_S is reached (Figure 4) which is sufficient to cause the rapid passage of a high current to the selected load. This injection of current takes place at the time t_6 in Figure 4 (which, at the limit, may be made to coincide with t_s) when the switch SW_i associated with the selected load is closed while all the other switches are open.

The first operating mode of the circuit of Figure 1, described with reference to Figure 3, is preferable since it is more convenient from an energy point of view. However, this operating mode is only possible if the supply is able to deliver sufficent current. When this does not occur, the circuit according to the invention nevertheless enables a rapid injection of current to the loads to be achieved by the charging and subsequent discharging of the capacitor C, as described with reference to Figure 4. The charging of C obviously takes a certain time, which depends on the intensity of the current which can be delivered by the supply. The unit ECU is correpsondingly programmed to start the charging of C correspondingly in advance of the time (t_6 in Figure 4) at which the passage of current to the selected load must be triggered.

In practice, the circuit of Figure 1 requires a single large-capacitance capacitor (the capacitor C) which is used for the injection of the current to the loads L_i in a predetermined sequential order actuated by the unit ECU by means of corresponding sequential piloting of the switches SW_i.

Capacitors C_i of considerably smaller capacitance are consequently sufficient to achieve any final inversion of the current in the loads.

Two ways in which the circuit of Figure 1 can cause a current to pass rapidly into a generic load to achieve the portions a and b of the ideal curve of Figure 2 have been described above. This current can be made to flow at the desired holding level (section d of the ideal curve shown in Figure 2) by the opening of the switch SW_1 or the switch SW_i associated with the load. In order subsequently to cancel out the current I_{Li} (stage $\underline{2}$) SW_i is opened. In this condition, a voltage is developed across the load which rises to high values in a short time. A clamping circuit is provided for limiting the value of this voltage and is constituted by the capacitor C_c to which the resistor R_c can be connected. It should be noted that this is a single circuit connected to all the loads L_i by means of the diodes D_c which are connected so as to form an OR circuit.

Together with the switch SW_3, the "clamping" circuit described above also enables the partial recovery of the reactive energy of the load which is excited from time to time, enabling this energy to be recycled towards the supply V_B. This energy recovery, which will now be described, takes place essentially each time a switch SW_i is opened after the injection of current to the associated load L. This can occur essentially in three circumstances, that is, when the current in the load L_i is changed from the maximum level to the holding level (section $\underline{c}$ of the ideal curve of Figure 2), when the current in the load is quenched (section $\underline{e}$ of Figure 2) and, although to a lesser extent, during the stages when the current in the load is being chopped, such as, for example, those described with reference to Figure 3.

Figure 5 shows examples of the traces of the current I_i in a load and of the voltage V_c across the clamping capacitor, and the corresponding stages of the switch SW_i associated with the load in question and of the switch SW_3. With reference to this Figure, when, at a time t_0, SW_3 is closed as a result of a command provided by the unit ECU and the switch SW_i associated with the energised load is closed, the current I_{Li} decays, whilst the voltage across the clamping capacitor rises. When the current I_H is reached in the load (a condition which can be detected by the unit ECU, for example, by means of a further Hall-effect sensor associated with L_i) at the time t_1, the unit ECU causes the switch SW_i which was previously been opened, to close again and opens SW_3. In these conditions, the clamping capacitor remains charged at the voltage to which it has previously been brought.

When, at the time t_2, the unit ECU subsequently opens SW_i, the current in the load decays rapidly, whilst the voltage V_c across the clamping capacitor rises rapidly, as shown in Figure 5, until the unit ECU closes SW_3 at the time t_3 and the voltage V_C consequently decreases rapidly.

During the stages when the current in the load which is energised from time to time is decaying, the closure of SW_3 enables part of the reactive energy stored in the load to be returned to the supply, by virtue of the concomitant action of the clamping circuit.

This characteristic may be of considerable interest for applications of the circuit according to the invention in the automotive field, particularly in motor cars provided with batteries and/or with relatively low power-recharging systems.

As far as R_c is concerned, this is only necessary (to dissipate the energy stored in C_c) if the circuit according to the invention is not arranged to recover the reactive energy. In this case, resistors, each connected in parallel with a diode D_c, may be provided in place of R_c.

Further possible applications of the circuit according to the invention are, for example, for controlling the relays which scan the punched cards or tapes in Jacquard-type textile machines, for controlling the electro-injectors of an Otto-cycle engine, for controlling the printing heads of matrix printers, etc.

Claims

1. A circuit for the piloting of inductive loads (L_i), particularly for operating the electro-injectors of a diesel-cycle internal combustion engine, comprising:
an input (1) for connection to a low-tension supply(V_B),
a storage coil (L_1) for storing energy delivered by the supply (V_B), and
electronic switching means (SW_1, SW_2, SW_i) for controlling the connection between the input (1), the storage coil (L_1) and each of the loads (L_i) in a predetermined manner to achieve a rapid transfer of current to each of the loads selectively,
characterised in that it also includes:
a capacitor (C) arranged in parallel with the branch circuits containing the loads (L_1), and connected to the coil (L_1) and the electronic switching means (SW_1, SW_2, SW_i), and
an electronic control unit (ECU) for piloting the electronic switching means (SW_1, SW_2, SW_i) according to a first operative mode in which, to transfer current into one of the loads (L_i), the switching means cause in succession, after the connection of the storage coil (L_1) to the supply (V_B):
the connection of the storage coil (L_1) to the capacitor (C) so as to form a resonant circuit, and then
the discharge of the resonant circuit (L_1, C) into the load (L_i).

2. A circuit according to Claim 1, further including a current-inversion capacitor (C_i) in parallel with each load (L_i) for enabling the current in the corresponding load (L_i) to be cancelled out rapidly, characterised in that each of the inversion capacitors (C_i) has a smaller capacitance than that of the said capacitor (C).

3. A circuit according to Claim 1 or Claim 2,characterised in that it also includes sensor means (S) for providing electrical signals indicative of the current delivered by the supply (V_B), and in that the control unit (ECU) is connected to the sensor means (S) and is arranged to pilot the electronic switching means (SW_1, SW_2, SW_i) in the first operative mode and in a second operative mode when the current delivered by the supply is greater than and less than a predetermined value, respectively, the unit (ECU) being adapted to cause the connection of the capacitor (C) to the supply (V_B) through voltage-boosting means (L_1, R_2) in the second operative mode, so as to charge the capacitor (C) to a predetermined voltage level greater than the voltage of the supply, and then the discharge of the energy stored in the capacitor (C) into a selected load (L_i).

4. A circuit according to Claim 3, characterised in that the sensor means comprise a shunt resistor in series with the storage coil (L_1).

5. A circuit according to Claim 3, characterised in that the sensor means comprise a galvanometric-effect sensor (S), particularly a Hall-effect sensor.

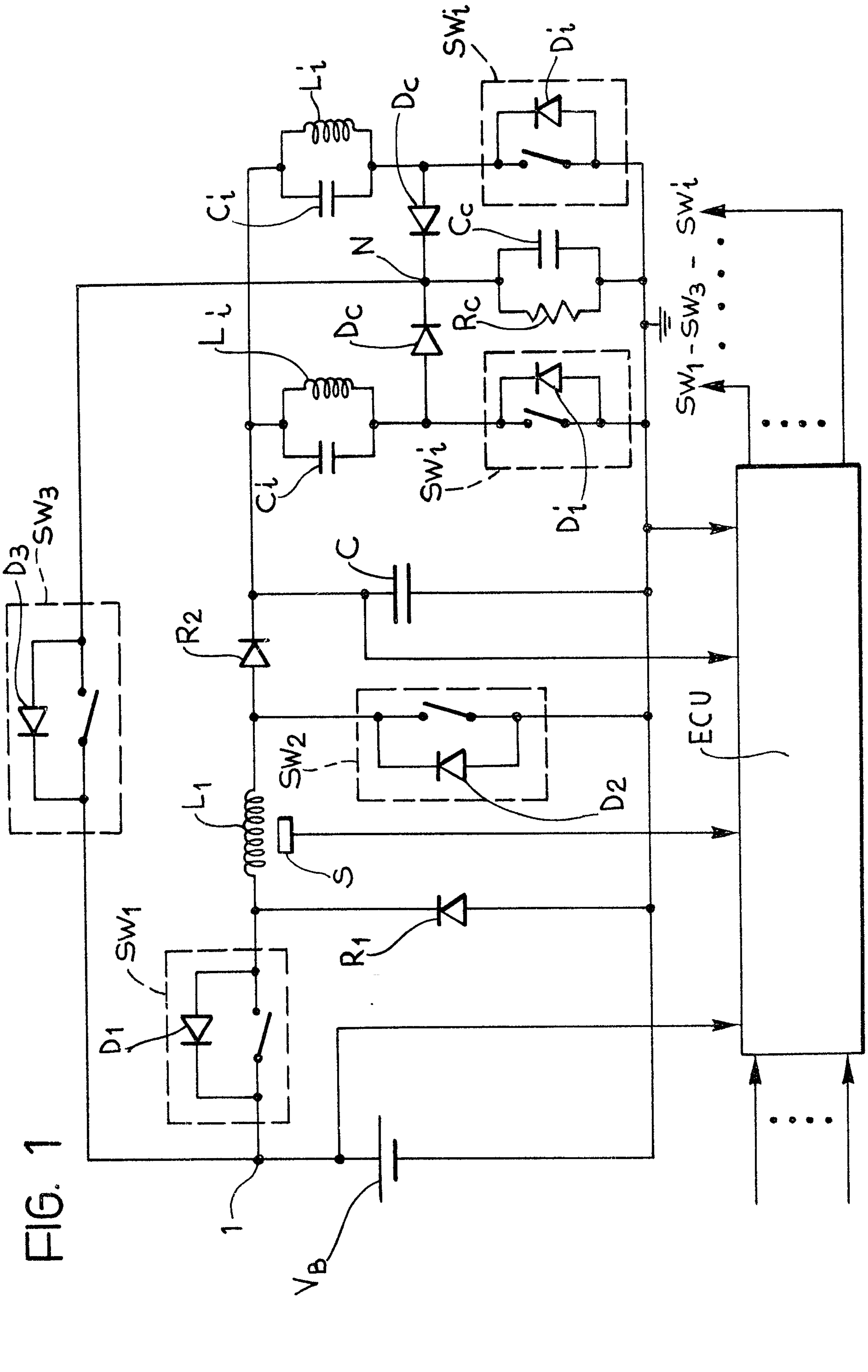
6. A circuit according to Claim 3, characterised in that the control unit (ECU) is adapted to detect the voltage across the capacitor (C).

7. A circuit according to any one of the preceding claims, comprising a plurality of branch circuits in parallel with each other, each of which includes a load (L_i), and in which the electronic switching means comprise
a first switch (SW_1) between the supply (V_B) and the storage coil (L_1),
a second switch (SW_2) in parallel with the branch circuits, and
a control switch (SW_i) in each of the branch circuits, between the corresponding load (L_i) and the supply (V_B),
characterised in that it also includes clamping circuit means (R_c; D_c) for limiting and possibly dissipating the voltage generated by each of the loads (L_i) when the associated control switch (SW_i) cuts off the current flowing into the load (L_i).

8. A circuit according to Claim 7, characterised in that the clamping circuit means comprise a clamping circuit of the parallel-RC type, and in that the loads (L_i) are connected to the clamping circuit by means of an OR circuit (D_c).

9. A circuit according to any one of the preceding claims, characterised in that it also includes energy-recovery circuit means (SW_3, R_c, C_c) controlled by the unit (ECU) and adapted to enable part of the reactive energy stored in the load (R_i) to be recycled towards the supply (V_b) each time a load (L_i) is deactivated.

10. A circuit according to Claims 8 and 9, characterised in that the recover circuit means include a further electronic switch (SW_3) connected between the clamping circuit (R_c, C_c) and the supply (V_B) and controlled by the electronic unit (ECU).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SW2
D2
R2
C
ECU
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Cc
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SW1 - SW3 - . . . . - SWi

FIG. 1

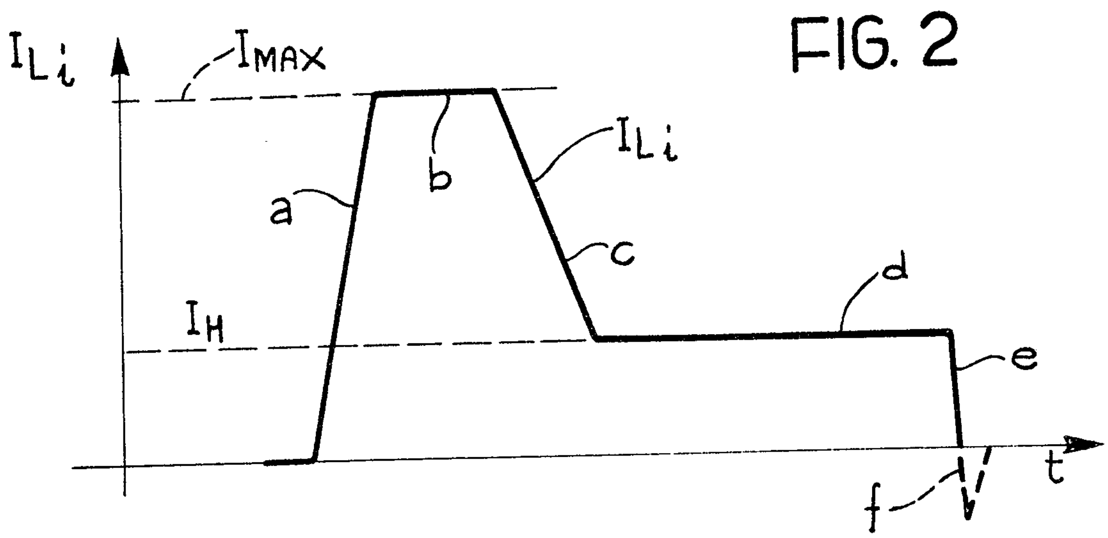
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FIG. 2

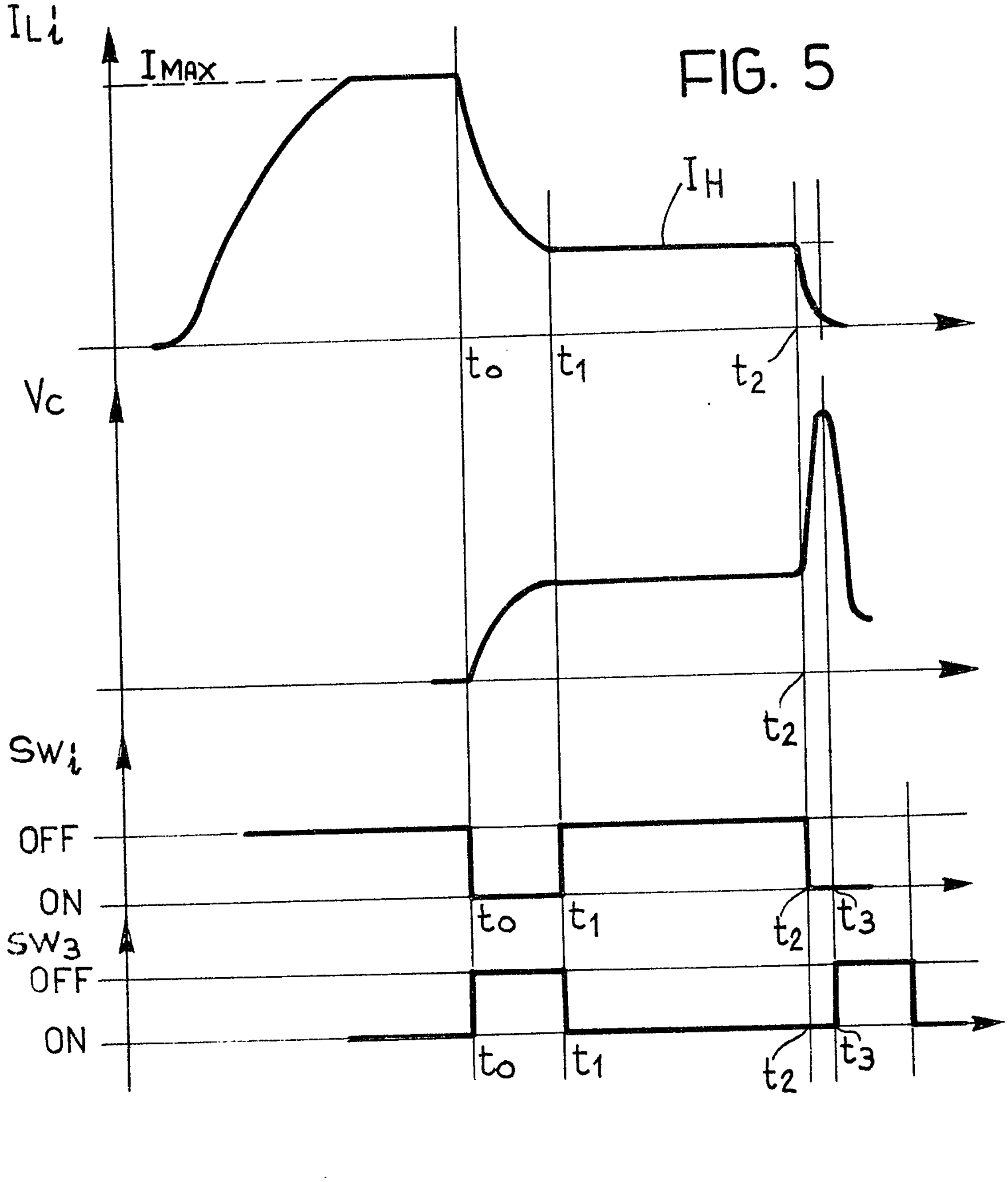
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FIG. 5

FIG. 3

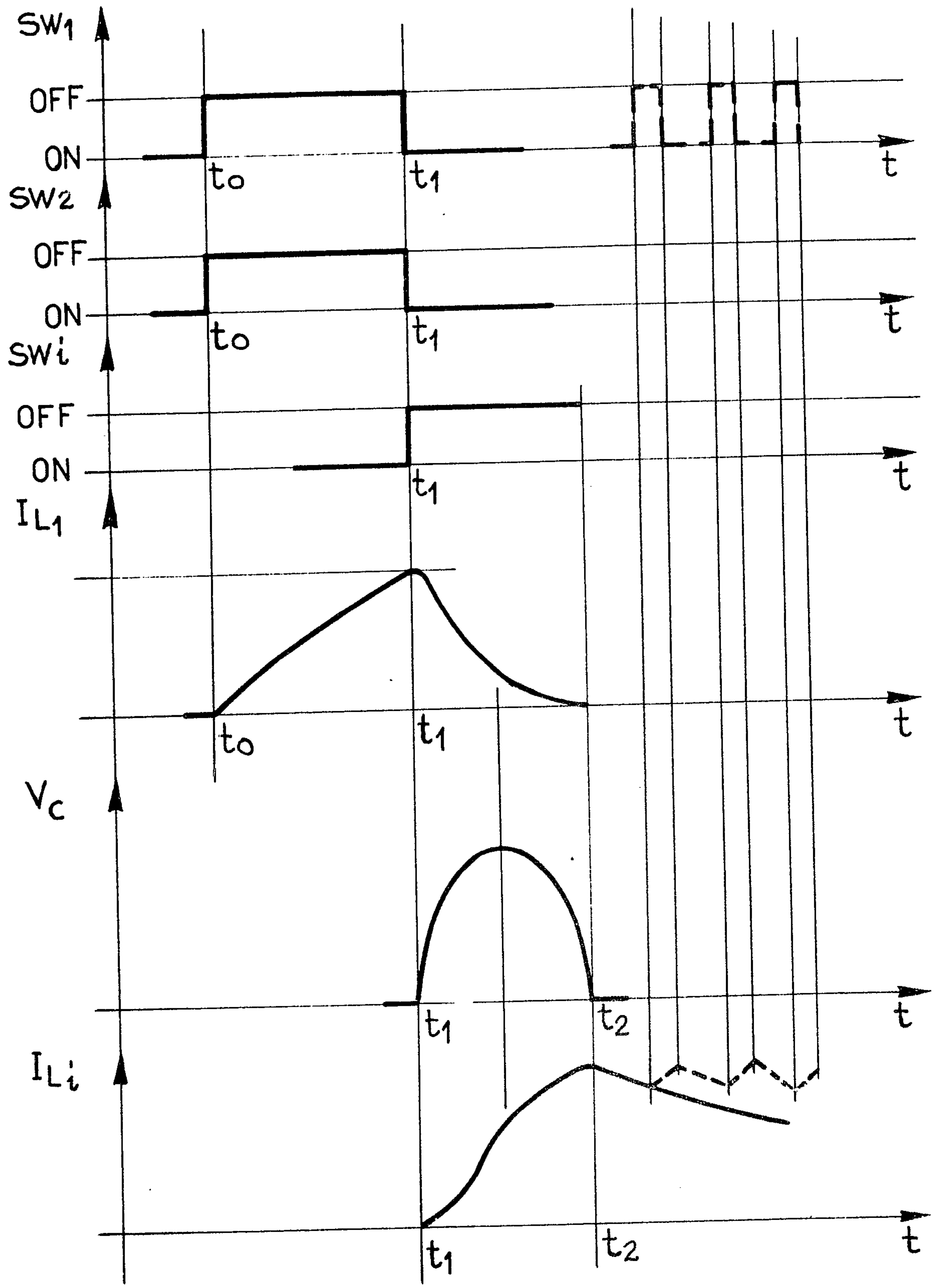
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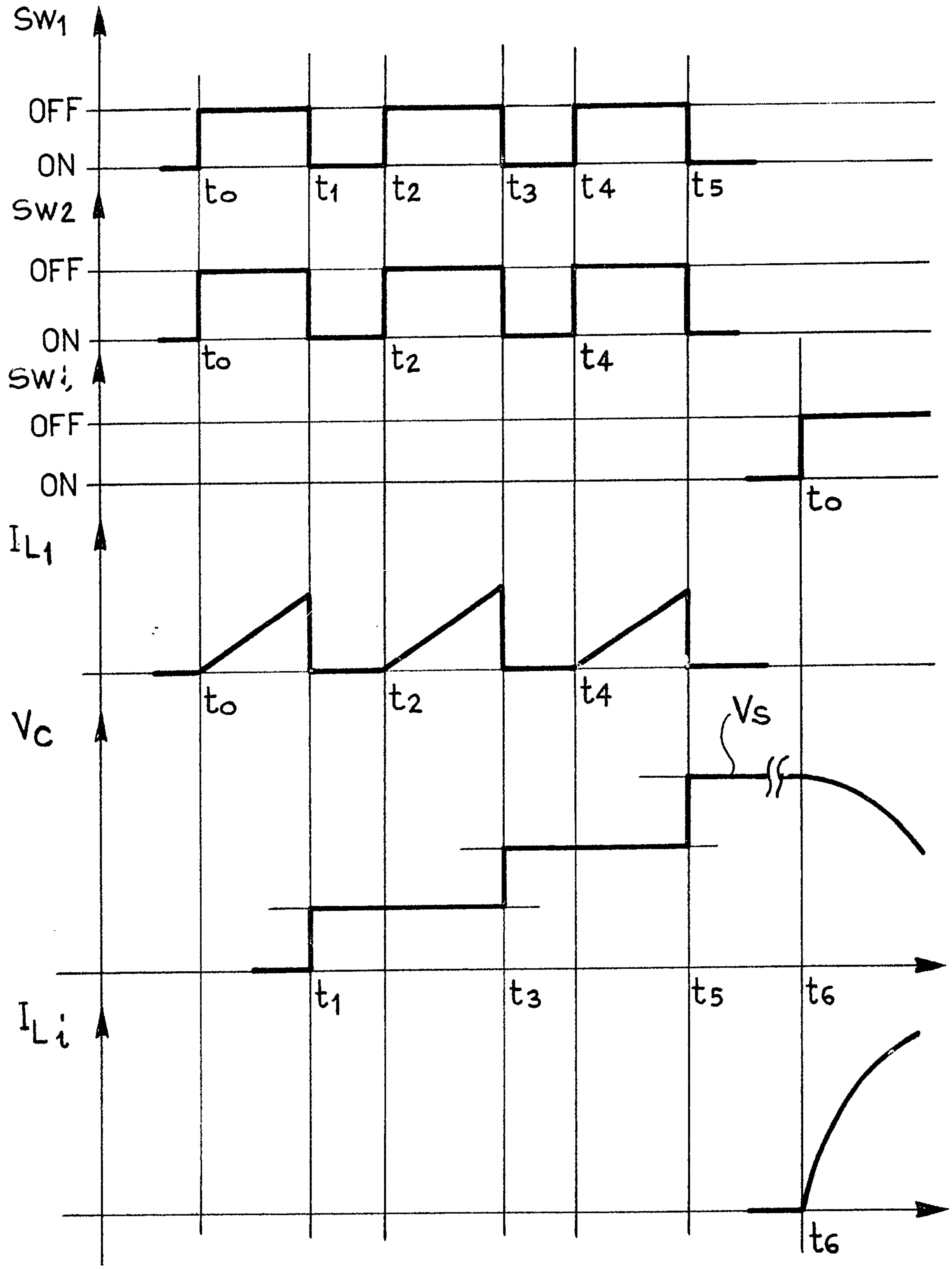
FIG. 4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EUROPEAN SEARCH REPORT

Application Number

EP 88 83 0336

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.4)
X	FR-A-2 533 263 (RENAULT) * Page 2, line 23 - page 7, line 19; figures *	1	F 02 D 41/20 H 03 K 17/04
D,A	GB-A-2 182 815 (IVECO FIAT) * Figures; page 1, lines 9-44; page 1, line 75 - page 2, line 89 *	1,2,7-9	
A	EP-A-0 034 076 (BENDIX) * Page 1, line 1 - page 7, line 37; page 9, line 16 - page 13, line 27; figures 1-4 *	1,2,7	
A	FR-A-2 538 942 (RENAULT) * Page 1, line 25 - page 6, line 9; figures 1,2,4 *	1-4,7-9	
A	EP-A-0 106 743 (BENDIX) * Page 1, line 24 - page 3, line 5; page 4, line 1 - page 5, line 4; page 16, line 2 - page 17, line 5; page 18, line 22 - page 20, line 21; page 22, lines 10-23; figures 1,3,7,8 *	1,3,4,6	TECHNICAL FIELDS SEARCHED (Int. Cl.4)
A	US-A-3 896 346 (ULE) * Figures 1,5; column 3, line 11 - column 7, line 5 *	1,3,4,7-10	F 02 D
A	DE-A-3 324 937 (MAGNET MOTOR GmbH) * Page 3, lines 1-10; page 3, line 31 - page 1, line 4; page 5, lines 17-36; page 7, line 21 - page 8, line 5; figures 1-3 *	1,3,5-10	

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	29-11-1988	LAPEYRONNIE P.J.F.

CATEGORY OF CITED DOCUMENTS

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