PATENT SPECIFICATION

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(19) THE PATENT OFFICE LONDON

(54) CONVERTERS

(71) We, CHLORIDE GROUP LIMITED, a Company registered under the laws of England, of 52 Grosvenor Gardens, London SW1W 0AU, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to converters. The invention is particularly applicable, although not limited, to high-frequency converters incorporated in electric battery charging apparatus supplied from a mains supply. In the usual form of charger if a step down or step up of voltage is required a transformer is necessary and even where there is no change of voltage a transformer will generally be required to ensure isolation of the battery from direct connection to the mains supply. In the case of a high-power charger the weight and bulk of a transformer for mains frequency will be very substantial, but if the frequency involved is increased to some kiloherz, for example 25 KHz, the weight and bulk are greatly reduced. In the case of a battery-driven vehicle this may make it practicable to carry the charger on the vehicle.

An object of the present invention is to provide a converter having a more nearly sinusoidal output than has been hitherto available.

According to the present invention a converter includes a resonant oscillatory tank circuit comprising a capacitor and an inductor, a switching circuit including a solid state switching device connected to apply a predetermined potential difference from a DV supply to the inductor, and synchronising means responsive to the oscillation of the oscillatory circuit for switching on the switching means for a fraction of a cycle only when the instantaneous value of the oscillatory potential difference across the inductor is already not less than a predetermined value, to delay the fall of the said oscillating potential difference and inject energy from the supply into the oscillatory circuit, and a load circuit coupled or connected to the tank circuit.

The switching circuit may include a solid state switching device in series with a diode. Alternatively or in addition it may include a solid state switching device in parallel with a diode.

In one form of the invention, the tank circuit comprises an inductor connected in series with a capacitor across the DV supply and the switching circuit is connected in parallel with the capacitor.

In another form of the invention, of push pull form, the converter includes a pair of supply capacitors connected in series with each other across the DV supply, and a pair of solid state switching devices each in series or in parallel with a diode, also connected in series with each other across the supply, and the inductor of the tank circuit is connected between the junction of the supply capacitors and the junction of the switching circuits.

The capacitor of the tank circuit may be connected between the junction of the switching circuits and one or each supply terminal, or it may be connected in parallel with the inductor.

The capacitor of the tank circuit may be shunted by a resistor, and may be connected in series with a solid state switching device for starting oscillation.

In one form of the invention the load circuit is connected or coupled to the tank circuit in parallel with the inductor.

Thus the load circuit may be connected to a secondary winding of a transformer having a primary winding in parallel with the inductor of the tank circuit. Alternatively, the load circuit may be connected to the secondary winding of a transformer of which the inductor of the tank circuit forms a primary winding. Again the load circuit may be coupled or connected to the tank circuit in series with the inductor, for example it may be connected to a secondary winding of a transformer having a primary winding in series with the inductor of the tank circuit.

The invention also embraces a battery charger incorporating the converter in combination with a rectifier to supply it from AC mains, a high-frequency transformer, and a rectifier for supplying unidirectional charging current.

Further features and details of the invention will be apparent from the following description of certain specific embodiments that will be given by way of example with reference to the accompanying drawings in which:

Figure 1 is a diagram of a known arrangement;

Figure 2 is a wave form diagram of the known arrangement of Figure 1;

Figure 3 is a schematic circuit diagram of one embodiment of the invention showing a single-ended parallel-load arrangement;

Figure 4 is a wave form diagram of the arrangement of Figure 3;

Figure 5 is a schematic circuit diagram of a push-pull parallel-load arrangement;

Figure 6 is a wave form diagram of the arrangement of Figure 5;

Figure 7 is a more detailed circuit diagram of an arrangement similar to that of Figure 5;

Figure 8 is a circuit diagram of a push-pull series-load arrangement;

Figures 9 and 10 are equivalent circuit diagrams illustrating the operation of the arrangement of Figure 8 in different portions of a cycle and;

Figures 11 and 12 are wave form diagrams illustrating the operation of the arrangement of Figure 8.

Figure 1 illustrates a typical known high-frequency converter operating from a DV source, shown as being derived from AC mains 15 through a rectifier 16 the purpose being to produce an isolated low voltage source of small dimensions. This technique is known generally as a chopped mode power supply. As shown in Figure 1, a pair of capacitors C1 and C2 are connected in series across the positive and negative DV supply terminals 10 and 11, the reactance of these capacitors being negligible at the converting frequency (which might typically be 30 KHz). A pair of transistors T1 and T2 are also connected in series across the terminals of the DV supply, while the primary winding of a transformer TR1 is connected between the junction of the capacitors and the junction A of the transistors. The transistors T1 and T2 are controlled by their base drives to switch on alternately. The output voltage of the transformer TR1 will be controlled by the mark space ratio of the conduction time of each of the two transistors. Figure 2 illustrates the voltage wave form appearing at the point A for two different output voltage conditions.

Due to the sharply changing voltage waveforms across the transistors the operating frequency and power output of such converters is severely limited by the permissible dissipation appearing across the switching devices on switch "on" and switch "off". Specifically on switch "off" the voltage appears across the device when the current flow through it is only slightly reduced, resulting in the high power condition of coincident high current and high voltage. A further undesirable feature of these converters, again due to the very high rates of change of voltage, is the radiated R.F. energy associated with the harmonics unavoidably present.

It is an object of this invention to produce a converter operating in a more nearly sinusoidal form, thus avoiding the drawbacks described above, and still achieve the necessary control of the output voltage.

Figure 3 shows an embodiment of the invention employing a single-ended form with parallel-connected load. The arrangement comprises a resonant oscillatory tank circuit consisting of an inductor L1 connected in series with a capacitor C3 across the supply terminals. As shown the supply terminals may be the terminals of a smoothing capacitor C8 connected to the output of a bridge rectifier 16 whereof the input is connected to A.C. supply terminals 15. At the frequency of the tank circuit, (conveniently 25 KHz) the reactance of the smoothing capacitor is negligible so that although the capacitor C3 and inductor L1 are connected in series across the supply, they are effectively a parallel tuned circuit at their resonant frequency.

A load circuit RL is connected in parallel with the inductor whilst a transistor T2 in seriees with a diode D2 are connected in parallel with the capacitor C3. The diode ensures that the transistor cannot be reverse biased even if the point A, namely the junction between the capacitor and inductor, goes negative.

The load RL may in fact be represented by the primary winding of a transformer connected in parallel with the inductor L1 or it may be the reflected impedence across L1 due to a loaded secondary winding magnetically coupled to L1; in other words L1 may be the primary winding of a transformer whose secondary winding is connected to a load, for example a rectifier connected to charge a secondary battery. The effect of this load is to damp the natural oscillation of the tank circuit by exracting energy from it.

The operation is as follows, considering the capacitor C3 discharged on initiating the supply. The transistor T2 is switched "on" transferring energy from the supply to the inductor. Current rises in the inductor at a rate determined by the value of inductance and the supply voltage. After a preset interval the transistor T1 is turned "off". The current flowing in the inductor is now transferred to the capacitor C3 and the potential at the point A rises sinusoidally. FIGURE 4 illustrates the waveform. Provided that RL does not load the tuned circuit heavily the point A describes the oscillatory path as shown. The excursions above and below zero are dependent on two factors, the damping effect of the load and the energy fed into the system in the period during which the transistor T2 conducts This period is variable and under the control of a feed back system, thus the amplitude of oscillation can be controlled to take account of load and supply variations. It should be noted that conduction of the transistor is only initiated when the voltage across it is zero or nearly so (this is determined by a sensing circuit which may take any of a number of well known forms for example as described below with reference to FIGURE 7). When the voltage across the transistor T2 is zero (whether or not the transistor is conducting), the voltage (a predetermined voltage) of the supply C8 is applied directly to the inductor L1. A termination of conduction the rate of rise of voltage is determined by the charging time of the capacitor C3 associated with the current flowing in both the inductor L1 and the load resistor RL. The high dissipation condition mentioned above is avoided.

If RL were to be short circuited the oscillation would cease and due to the action of the sensing circuit mentioned above the transistor T2 would not be turned on. On removal of the short circuit, oscillations may be re-initiated by a number of alternative methods.

Figure 5 shows a push-pull version of the above, Figure 6 illustrating the waveform.

The circuit comprises a pair of supply capacitors C1 and C2 connected in series across the supply terminals 11 and 10, a pair of transistors T1 and T2 each in series with a diode D1 or D2, also connected in series across the supply terminals. An inductor L1 in parallel (or effectively in parallel) with a load resistor RL is connected between the junction of the capacitors C1 and C2, and the junction between the transistor T1 and diode D2. To complete the tank circuit a capacitor C3 shunted by a resistor R1, is connected through a triac X1 across the transistor T2 and diode D2. The push-pull circuit operates in a similar manner to that of Figures 3 and 4 but with of course two conducting periods per cycle, instead of one, as indicated in Figure 6.

The triac X1 is provided to initiate oscillations. The capacitor C3 discharged by virtue of the resistor R1, is charged when the triac is fired into conduction and oscillations commence. Due to the high frequencies involved, it would be unnecessary to refire the triac during normal operation.

Clamping diodes D3 and D4, shown on Figure 5 are connected between each of the supply rails and a suitable tapping point on the inductor L1. These diodes limit the voltage appearing across the inductor L1, and therefore, the transistors T1 and T2, to a predetermined safe value in the event of an open-circuit appearing on the output of the convertor or, during the initiation of circuit oscillations.

The switching devices referred to above have been illustrated as transistors, but may be any suitable electronic switching devices such as thyristors of various types etc.

A starting circuit comprising a thyristor TH1 connected in parallel to a reverse-connected diode D3, as shown in Figure 7, can be used to replace the triac X1 of Figure 5. The operation of this starting circuit is described later.

Figure 7 shows an arrangement similar to that of Figure 5 in greater detail. Thus the capacitors C1 and C2 will be seen on the right of the figure connected in series across the power supply terminals 11 and 10. Similarly, the transistors T1 and T2 each in series with a diode D1 or D2 will be seen connected in series with each other across the same pair of terminals, whilst the junction between the transistors and the junction between the capacitors are connected through the inductor L1 which is shunted by a resistor RL, which, as indicated above, may be a primary winding of a transformer or a winding inductively coupled to the inductor L1.

The capacitors C1 and C2 share the supply voltage resistors R3 and R4 serving to compensate for unequal leakage currents, so that the potential at the junction of C1 and C2 with respect to the earthed terminal 10 is half the potential at the terminal 11. The inductor L1 and a capacitor C3 form a tuned tank circuit. Power is fed into the "tank" circuit by the alternate conduction of the transistors T1 and T2, the diodes D1 and D2 preventing reverse transistor current.

It is believed that the remainder of the circuit will be clear from the diagram, taken with the following description of its operation.

Starting is achieved by firing a Thyristor Th1. As described below a logic system on the left of the diagram senses the potential at the point A; if this is negative with respect to the line 10 the drive circuit to the transistor T2 is initiated, whereas if the point A is positive with respect to the line 11 the drive circuit to the transistor T1 is initiated. Initially a switch S1 is open, the thyristor Th1 non-conducting, and the capacitor C3 charges via a resistor R1 and the inductor L1 so that its bottom plate is positive with respect to the point A. A capacitor C4 also charges via resistors R1 and R2. Closing the switch S1 (which may be effected manually or electronically) fires the thyristor Th1 which "grounds" the bottom plate of the capacitor C3; the capacitor C4 provides latching current for the thyristor Th1. The point A is thus driven negative with respect to ground, initiating the drive to transistor T2. Thereafter, the thyristor Th1 remains in conduction, reverse currents being by-passed by a diode D3.

Clamping diodes D8 and D9 are included as in Figure 5 to limit the voltage appearing across the transistors T1 and T2 during initiation of circuit oscillations and in the event of an open-circuit appearing on the output of the converter.

Considering now the logic system, two identical circuits are employed providing the drive to each of the transistors T1 and T2 in turn. When the point A falls below the potential of the negative line 10, current flows via a resistor R5 a diode D5 and a light emitting diode D7. When the point A rises above the potential of the positive line 11 current flows via the resistor R5 a diode D4 and a light emitting diode D6. The L.E.D.'s form part of opto-isolators, the diode D7 being associated with a transistor T101 and the diode D6 with a transistor T201.

Conduction of the transistor T101 turns on a transistor T102 the output of which is differentiated by a capacitor C102 into the base of a transistor T103. The resultant negative going pulse at the collector passes through a diode D102 to trigger an integrated circuit IC1 co-operating with a resistor VR, and a capacitor C6 to form a timer of which the timing period now commences. Simultaneously with the triggering of the timer, a further integrated circuit IC101 here connected as a flip-flop is triggered by the pulse from the collector of the transistor T103. The output of the integrated circuit IC1 "going high" removes the reset signal, triggering being therefore effected directly by the transistor T103. The output of the integrated circuit IC101 "going high" turns on a transistor T104 energising a primary winding of a transformer TR1 which provides base drive to the transistor T2. With the circuit IC101 high, a transistor T107 is held on, removing the base drive of a transistor T106.

At the end of the timing period of the timer IC1, its output "goes low" resetting the integrated circuit IC101 removing the base drive to the transistors T104 and T107. The transistor T106 thus "turns on", energising a second primary winding of the transformer TR1 and applying reverse base drive to T2 turning it off.

The circuit associated with the drive to the transistor T1 performs in an identical manner being initiated by the opto-isolator consisting of the diode D6 and transistor T201, (other corresponding components bearing numbers 200 odd instead of 100 odd). It should be noted that common timing components i.e. VR1, R7, C6, and IC1 are used for both circuits.

It should further be noted that the timing periods commence when the potential of the point A becomes more positive than the positive line 11 or more negative than the negative line 10, but due to the diodes D5 and D6 power can only be transferred from the supply to the tank circuit when the said potential gain has passed through that of the said line and the respective transistor and diode become forward biased. Thus the circuit is to a large degree self regulating under conditions of constant load and supply voltage. Any increase in the amplitude of oscillation will reduce the conduction period and hence energy transfer and vice versa.

The power output can be varied by adjustment of the variable resistor VR1 to vary the resistance of the resistor capacitor timer IC1.

In the arrangements of Figures 3 to 7 with the load in parallel with the inductor of the tank circuit, control is effected by increasing or decreasing the amplitude of the tank oscillations. In the case where the load is a battery the amplitude must vary in response to the state of charge of the battery and thus its terminal voltage. Permitting the voltage to rise above the positive rail or fall below the negative achieves this objective. This implies the use of switching devices rated to withstand voltages considerably in excess of the supply.

In the circuit shown in Figure 8, totally different considerations apply. The voltage excursion of the point A is constrained to the supply rails by diodes D9 and D10, with the load illustrated by a transformer, connected in series with the inductor of the tank circuit. The tank capacitor C3 is connected in parallel with the combination.

Figure 9 shows the equivalent circuit during the conduction of one or other of the switching transistors when used for charging a battery the load voltage shown as VL is of course the reflected voltage appearing across the transformer primary of the actual battery connected across the rectified secondary output. R denotes the system resistance which can be ignored.

Figure 10 shows the equivalent circuit during the non conduction periods of the switching transistors.

Thus with the transistor T2 conducting current IL will rise in the inductor L1, linearly at a rate determined by the difference between V/2 and the reflected load voltage and the circuit constants. After a given time transistor conduction is terminated and the potential of the point A rises sinusoidally towards the positive supply line. It will be assumed that sufficient energy has been supplied during the conduction of one device to ensure that the point A attains the potential of the opposite rail when or before the current in the tank circuit falls to zero. If zero, the second device conducts immediately the point A attains the rail potential, if not, current is initially passed back to the supply via the parallel diode, the transistor then turns on. Load current, i.e. tank current, can be controlled by varying the conduction time of the switching devices. Figure 11 illustrates the voltage and current waveforms for zero tank currents at reversal, Figure 12 shows the same waveforms for non-zero condition.

WHAT WE CLAIM IS:—

1. A converter including a resonant oscillatory tank circuit comprising a capacitor and an inductor, a switching circuit including a solid state switching device connected to apply a predetermined potential difference from a DV supply to the inductor, and synchronising means responsive to the oscillation of the oscillatory circuit for switching on the switching means for a fraction of a cycle only when the instantaneous value of the oscillatory potential difference across the inductor is already not less than a predetermined value, to delay the fall of the said oscillating potential difference and inject energy from the supply into the oscillatory circuit, and a load circuit coupled or connected to the tank circuit.

2. A converter as claimed in Claim 1 in which the switching circuit includes a solid state switching device in series with a diode.

3. A converter as claimed in Claim 1 in which the switching circuit includes a solid state switching device in parallel with a diode.

4. A converter as claimed in any one of the preceding claims in which the tank circuit comprises an inductor connected in series with a capacitor across the DV supply and the switching circuit is connected in parallel with the capacitor.

5. A converter as claimed in any one of Claims 1 to 3 of push pull form which includes a pair of supply capacitors connected in series with each other across the DV supply, and a pair of solid state switching devices each in series with a diode also connected in series with each other across the supply, and in which the inductor of the tank circuit is connected between the junction of the supply capacitors and the junction of the switching circuits.

6. A converter as claimed in any one of Claims 1 to 3 of push pull form which includes a pair of supply capacitors connected in series with each other across the DV supply, and a pair of solid state switching devices each in parallel with a diode also connected in series with each other across the supply, and in which the inductor of the tank circuit is connected between the junction of the supply capacitors and the junction of the switching circuits.

7. A converter as claimed in Claim 5 or Claim 6 in which the capacitor of the tank circuit is connected between the junction of the switching circuits and one or each supply terminal.

8. A converter as claimed in Claim 5 or Claim 6 in which the capacitor of the tank circuit is connected in parallel with the inductor.

9. A converter as claimed in any one of Claims 5 to 8 in which the capacitor of the tank circuit is shunted by a resistor.

10. A converter as claimed in any one of Claims 5 to 9 in which the capacitor of the tank circuit is connected in series with a solid state switching device for starting oscillation.

11. A converter as claimed in any one of the preceding Claims in which the load circuit is connected or coupled to the tank circuit in parallel with the inductor.

12. A converter as claimed in Claim 11 in which the load circuit is connected to a secondary winding of a transformer having a primary winding in parallel with the inductor of the tank circuit.

13. A converter as claimed in Claim 11 in which the load circuit is connected to the secondary winding of a transformer of which the industor of the tanks circut forms a primary winding.

14. A converter as claimed in any one of Claims 1 to 11 in which the load circuit is coupled or connected to the tank circuit in series with the inductor.

15. A converter as claimed in Claim 14 in which the load circuit is connected to the secondary winding of a transformer having a primary winding in series with the inductor of the tank circuit.

16. A converter as claimed in any one of the preceding Claims in which the frequency of the tank circuit is at least 1 KHz.

17. A converter as claimed in Claim 16 in which the frequency of the tank circuit is of the order of 25 KHz.

18. A battery charger incorporating a converter as claimed in any one of the preceding Claims in combination with a rectifier to supply it from A.C. mains, a high-frequency transformer and a rectifier for supplying uni-directional charging current.

19. A converter as specifically described herein with reference to Figures 3 and 4, Figures 5 and 6, or Figure 7, or Figures 8 to 12, of the accompanying drawings.

KILBURN & STRODE,
Chartered Patent Agents,
Agents for the Applicants.

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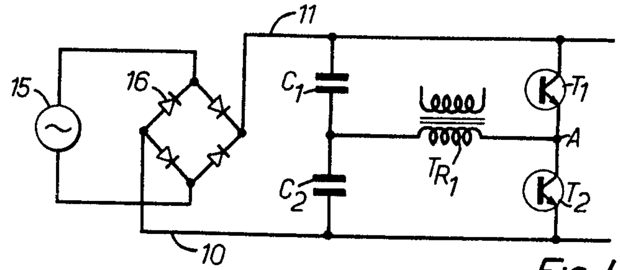

FIG. 1.

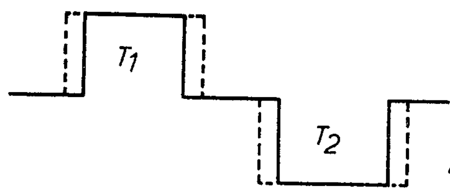

FIG. 2.

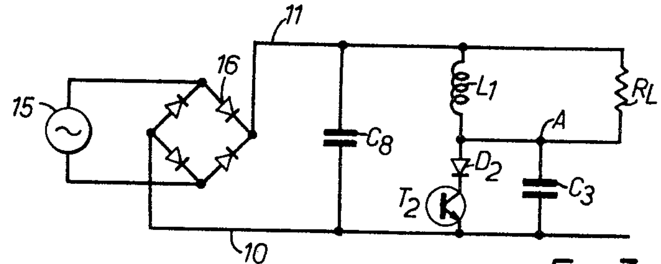

FIG. 3.

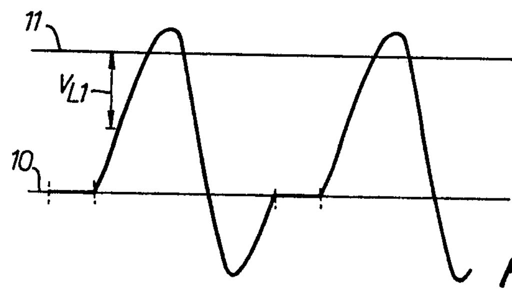

FIG. 4.

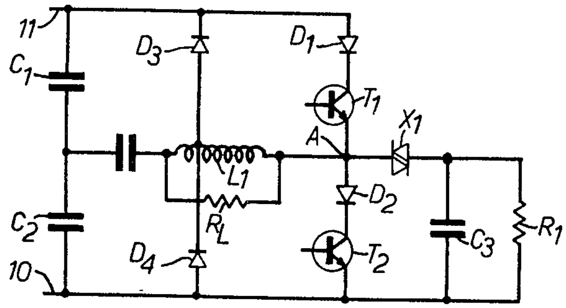

FIG. 5.

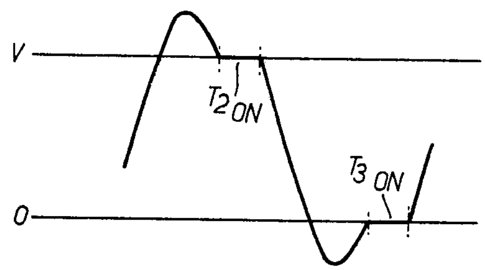

FIG. 6.

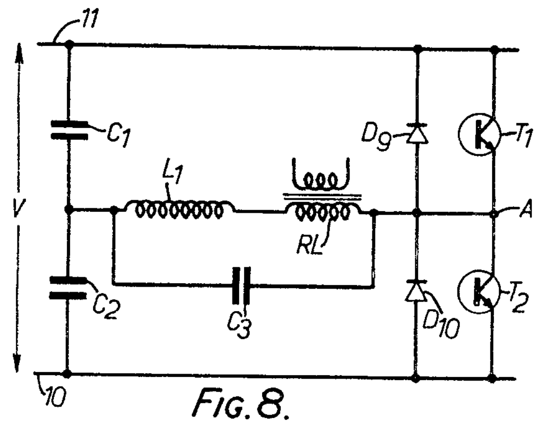

FIG. 8.

1602613 COMPLETE SPECIFICATION

4 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 3

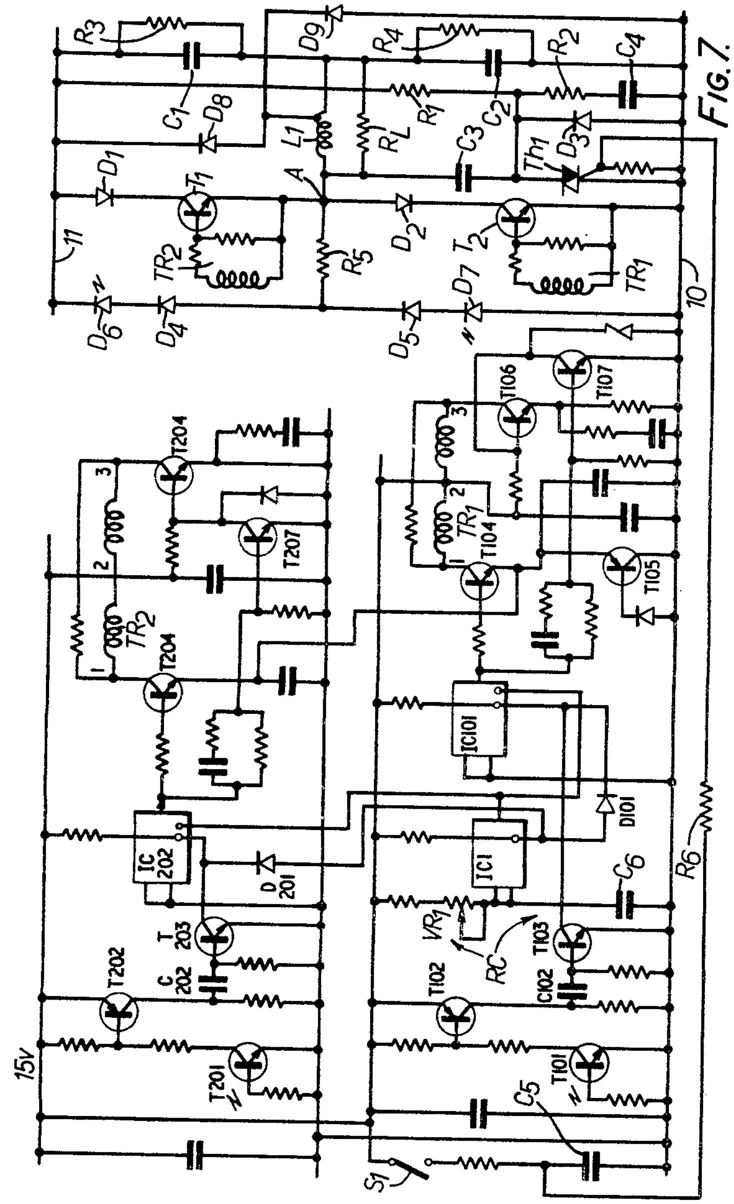

FIG. 7.

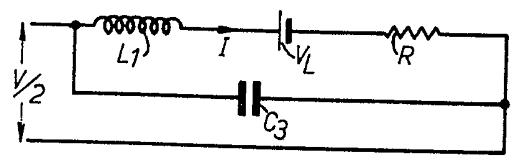

FIG. 9.

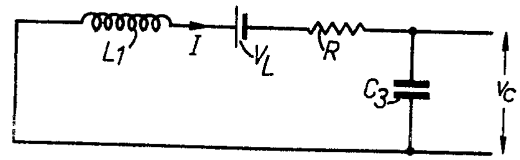

FIG. 10.

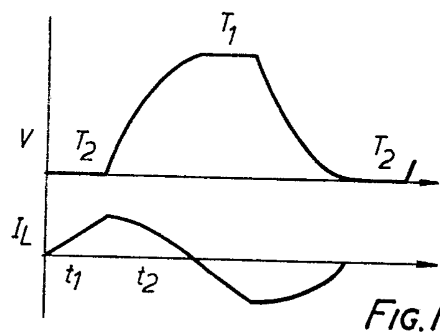

FIG. 11.

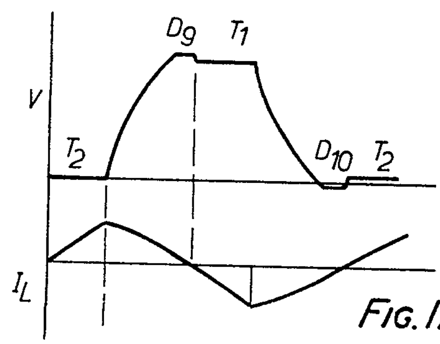

FIG. 12.