

PATENT SPECIFICATION

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(54) IMPROVEMENTS IN OR RELATING TO CONVERTER CIRCUITS

(71) We, HEWLETT-PACKARD COMPANY, a corporation organized and existing under the laws of the State of California, United States of America, of 1501 Page Mill Road, Palo Alto, California 94304, U.S.A., 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:—

The invention is concerned with improvements in or relating to converter circuits.

Certain known D.C.—to—D.C. converter circuits which use a pair of transistors connected to operate substantially in push-pull manner commonly have poor efficiency because of turn-on and turn-off losses introduced in each operating cycle by the two transistors. More importantly, since the saturable core of such known converter circuits is driven between oppositely-poled limits of saturation flux, such converters may not be controlled conveniently without altering the operating wave shapes, and the like.

It is an object of the present invention to provide a high efficiency voltage level converter circuit which requires only a single transistor and does not require driving a saturable core between oppositely poled limits of saturation flux.

The present invention provides a converter circuit including:

a gain element having a plurality of electrodes forming an output conduction circuit and a conduction control circuit, the output conduction circuit being conductive in response to a signal of one polarity applied to the conduction control circuit;

an inductive element having a plurality of windings disposed on a saturable core;

a utilization circuit;

means for serially connecting the output conduction circuit of the gain element, the utilization circuit and a first winding of the

inductive element to receive input power for building up magnetic flux in the inductive element during conduction of said gain element;

a first diode;

means for connecting the first diode across the electrodes forming the conduction control circuit of the gain element with a conduction polarity which conducts current in response to signal of polarity which conducts current in response to signal of polarity opposite to said one polarity applied to the conduction control circuit;

means for applying a control signal to a second one of the windings for operatively establishing a control level of flux in the saturable core of said inductive element to control the conduction period of the gain element;

a capacitor; and

means for serially connecting a third winding and the capacitor across the electrodes forming the conduction control circuit to forward bias the first diode and permit current flow through the serially connected capacitor, first diode and third winding as flux in the inductive element collapses following cessation of conduction of the gain element upon saturation of the inductive element, said current flow adjusting the voltage across the capacitor to a value which, in conjunction with the voltage across said third winding supplies a signal of said one polarity to the conduction control circuit to render said gain element conductive in response to the magnetic flux in the inductive element reducing substantially to said control level of flux.

Preferably the output conduction circuit is formed by a first and a second of said plurality of electrodes, and the conduction control circuit is formed by the second and a third of said plurality of electrodes. The control circuit winding provides regenerative feedback to cause oscillation, and switching of

the gain element between conducting and non-conducting conditions is initiated as a result of the current in the series circuit rising to a value at which the core saturates.

5 Preferably, said utilization circuit includes a transformer having its primary winding connected in said series circuit and having its secondary winding magnetically coupled to said primary winding, a rectifier connected to said secondary winding and poled to be reverse biased in response to a signal appearing thereacross during conduction of current through the output conduction circuit of said gain element and said source of control current includes a comparator having an input connected to a source of a reference signal and having another input connected to receive the rectified signal from the secondary winding of said transformer, said comparator also having an output connected for applying to the second winding of said inductive element a control signal which is indicative in magnitude and polarity of the different between the signals applied to the inputs of the comparator.

There now follows a detailed description which is to be read with reference to the accompanying drawings of a converter circuit which is illustrative of the present invention; it is to be clearly understood that this illustrative converter circuit has been selected for description to illustrate the invention by way of example and not by way of limitation.

In the drawings:—

Fig. 1 is a schematic diagram of the preferred embodiment of the present converter circuit; and

Fig. 2 is a graph showing the operating flux levels in the saturable inductor in the circuit of Fig. 1.

Referring now to the schematic diagram of Fig. 1 and the graph of Fig. 2, there is shown the illustrative converter circuit which comprises a gain element provided by a single transistor 9 and two separate inductive elements 11 and 13. The inductive element 11 includes a saturable core which has a B—H characteristic 15 as shown in Fig. 2 and the core of the inductive element 13, which is a transformer of a utilization circuit of the illustrative converter circuit, is selected to have high limits of saturation flux so that it cannot saturate during normal operation. The inductive element 11 includes first and third windings 19 and 17, the former one 19 of which is serially connected with the emitter-collector circuit of the transistor 9 and the primary winding 20 of the element 13 between terminals 21, 23 of a D.C. power source. In addition, the element 11 includes a second control winding 25 which is coupled to a source 27 of control current for altering the conduction time of the transistor 9 and thereby regulating the

output to the utilization circuit which also includes a circuit 29 which is operated by the illustrative converter circuit. The turns of the windings 17, 19 and 25 of the element 11 are typically in the ratios of 5 to 1 to 5 respectively.

In operation, the circuit of Fig. 1 receives a D.C. supply (or a slowly varying supply) at terminals 21 and 23 and supplies a rectified steady or stable D.C. signal, typically at a different level, to the utilization circuit 29. Initially, current flows in the series circuit which includes the winding 20 (element 13), the winding 19 and the collector-emitter circuit of the transistor 9. The voltage induced in the winding 17 is of a polarity such that, when applied through a capacitor 22 and a diode 24 across the base-emitter junction of the transistor 9, tends to turn the transistor on hard. The voltage drops across the conducting transistor 9 and across the winding 19 are very small so that substantially the entire input voltage across the terminals 21, 23 appears across the winding 20. The current i builds up substantially linearly with time in accordance with the relationship:

$$E_1 = L_{20} \times \frac{di}{dt}$$

where L_{20} is the inductance of the winding 20 and E_1 is the voltage applied at the terminals 21, 23. A rectifying diode 31 connected to the secondary winding 33 of the element 13 is poled to remain reverse biased during the change of input current i with time so that the element 13 (which does not saturate) stores energy at a level proportional to $\frac{1}{2} L_{20} i^2$.

At some instant during the build up of the input current i , the core of the element 11 saturates (as shown in Fig. 2), thereby decoupling the windings 17 and 19 and turning off the transistor 9 and abruptly terminating current flow through the winding 20. This produces an abrupt polarity reversal across the winding 33, thereby allowing the energy stored in the element 13 to be transferred to an output capacitor 35 through the rectifying diode 31 and an inductor 37. At the same time, an abrupt polarity reversal also occurs across the winding 17 of the element 11, thereby forward biasing a diode 18 and permitting the energy stored in the element 11 to establish current flow through the diode 18 and the capacitor 22. The flux level in the core of the element 11 is thus decreased from the saturation level 30 to the lower level that is determined by the control winding 25. Current flowing in this winding (i.e. flowing in at the dot end, as shown) biases the core (level 32 in Fig. 2) opposite to that estab-

lished by the current flow in the winding 19. In the absence of the control current, the core of the element 11 may be reset to a level 34 which is below the saturation flux limit 30 and which corresponds to voltage stored by the capacitor 22 that again turns on the transistor 9 for another complete cycle of operation.

Resetting the core of the element 11 to different flux levels 32—36 below the saturation flux limit 30 alters the time during which the transistor 9 conducts the steadily-increasing current i and the level of current i , at which current flow is interrupted, thus determines the voltage across the output capacitor 35. This output voltage may be compared with a reference voltage V_{ref} in a suitable source 23 of control current such as an amplifier 27, or the like, to supply control current to the winding 25 of element 11. For longer conduction time, the current i attains a higher level 38 thereby establishing a higher output voltage across the capacitor 35. In this way, the circuit of the present invention converts a D.C. supply at the input terminals 21, 23 to an output D.C. signal across the capacitor 35 and also provides output regulation to compensate for changes in the input voltage, the output voltage and the output current.

WHAT WE CLAIM IS:—

1. A converter circuit including:
 - a gain element having a plurality of electrodes forming an output conduction circuit and a conduction control circuit, the output conduction circuit being conductive in response to a signal of one polarity applied to the conduction control circuit;
 - an inductive element having a plurality of windings disposed on a saturable core;
 - a utilization circuit;
 - means for serially connecting the output conduction circuit of the gain element, the utilization circuit and a first winding of the inductive element to receive input power for building up magnetic flux in the inductive element during conduction of said gain element;
 - a first diode;
 - means for connecting the first diode across the electrodes forming the conduction control circuit of the gain element with a conduction polarity which conducts current in response to signal of polarity opposite to said one polarity applied to the conduction control circuit;
 - means for applying a control signal to a second one of the windings for operatively

establishing a control level of flux in the saturable core of said inductive element to control the conduction period of the gain element;

a capacitor; and

means for serially connecting a third winding and the capacitor across the electrodes forming the conduction control circuit to forward bias the first diode and permit current flow through the serially connected capacitor, first diode and third winding as flux in the inductive element collapses following cessation of conduction of the gain element upon saturation of the inductive element, said current flow adjusting the voltage across the capacitor to a value which, in conjunction with the voltage across said third winding supplies a signal of said one polarity to the conduction control circuit to render said gain element conductive in response to the magnetic flux in the inductive element reducing substantially to said control level of flux.

2. A converter circuit according to claim 1 wherein the output conduction circuit is formed by a first and a second of said plurality of electrodes, and the conduction control circuit is formed by the second and a third of said plurality of electrodes.

3. A converter circuit according to either one of claims 1 and 2 wherein said utilization circuit includes a transformer having its primary winding connected in said series circuit and having its secondary winding magnetically coupled to said primary winding, a rectifier connected to said secondary winding and poled to be reverse biased in response to a signal appearing thereacross during conduction of current through the output conduction circuit of said gain element, and said source of control current includes a comparator having an input connected to a source of a reference signal and having another input connected to receive the rectified signal from the secondary winding of said transformer, said comparator also having an output connected for applying to the second winding of said inductive element a control signal which is indicative in magnitude and polarity of the difference between the signals applied to the inputs of the comparator.

4. A converter circuit according to claim 1 substantially as hereinbefore described with reference to the accompanying drawings.

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 - means for serially connecting the output conduction circuit of the gain element, the utilization circuit and a first winding of the inductive element to receive input power for building up magnetic flux in the inductive element during conduction of said gain element;
 - a first diode;
 - means for connecting the first diode across the electrodes forming the conduction control circuit of the gain element with a conduction polarity which conducts current in response to signal of polarity opposite to said one polarity applied to the conduction control circuit;
 - means for applying a control signal to a second one of the windings for operatively

establishing a control level of flux in the saturable core of said inductive element to control the conduction period of the gain element;

a capacitor; and

means for serially connecting a third winding and the capacitor across the electrodes forming the conduction control circuit to forward bias the first diode and permit current flow through the serially connected capacitor, first diode and third winding as flux in the inductive element collapses following cessation of conduction of the gain element upon saturation of the inductive element, said current flow adjusting the voltage across the capacitor to a value which, in conjunction with the voltage across said third winding supplies a signal of said one polarity to the conduction control circuit to render said gain element conductive in response to the magnetic flux in the inductive element reducing substantially to said control level of flux.

2. A converter circuit according to claim 1 wherein the output conduction circuit is formed by a first and a second of said plurality of electrodes, and the conduction control circuit is formed by the second and a third of said plurality of electrodes.

3. A converter circuit according to either one of claims 1 and 2 wherein said utilization circuit includes a transformer having its primary winding connected in said series circuit and having its secondary winding magnetically coupled to said primary winding, a rectifier connected to said secondary winding and poled to be reverse biased in response to a signal appearing thereacross during conduction of current through the output conduction circuit of said gain element, and said source of control current includes a comparator having an input connected to a source of a reference signal and having another input connected to receive the rectified signal from the secondary winding of said transformer, said comparator also having an output connected for applying to the second winding of said inductive element a control signal which is indicative in magnitude and polarity of the difference between the signals applied to the inputs of the comparator.

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