

INVERTER FOR FEEDING A CONSUMING DEVICE HAVING AN
INDUCTIVE COMPONENT

The invention relates to an inverter which produces, from a direct voltage, an alternating voltage for a consuming device having an inductive component. The frequency of the alternating voltage produced may be of the order of magnitude of 10-100 kHz, particularly about 30 KHz.

Consuming devices of somewhat the following type can be fed with the alternating voltage produced: alternating current motors without commutation, inductors, transformers, fluorescent tubes which work at a frequency of about 30 kHz, and boiling plates with inductive heating, in the case of which only the receiving container for the food is heated by a magnetic field in each case.

Inverters are known (Eleketronique Industrielle No.50/1-04-1983, pages 35-41) wherein a direct voltage is applied to a so-called half-bridge with two power transistors connected in series. The power transistors are controlled alternately so as to be conducting and, at their connecting point, produce the alternating voltage for the consuming device. Theoretically, the first transistor ought to be switched off at a certain moment and the second transistor switched on at the same moment. The inductive component of the consuming device does not permit any sudden interruption of the current. On the other hand, the transistors would

be endangered if they were both to be conducting for a short time. Because of tolerances and the depletion times of the transistors, such a precise switching is only possible with complicated driver circuits in the form of microprocessors.

It is therefore known, for safety, to provide, between the successive conducting phases of the two transistors, a quiescent time, during which both transistors are non-conducting. As a result, assurance is provided that both transistors cannot conduct simultaneously. In order to render possible the necessary flow of current during this quiescent time, diodes are connected in parallel with the transistors, being poled oppositely to the collector-emitter current paths of the transistors and taking over the current briefly during the quiescent time. Connected in parallel with each of the diodes is a capacitor which limits the steepness of the alternating voltage produced.

In this case the two transistors are controlled alternately, in push-pull, so as to be conducting and cut-off, by windings of a transformer. For this purpose, an additional driver circuit must be associated with the transformer to cause this control of the transistors. Such a driver circuit requires additional expense on circuitry and power. The driver circuit may, for example, be an additional stage which is fed with a separate operating voltage.

It is the object of the present invention to reduce the expenditure on circuitry and the expenditure of energy for the control of the transistors.

The invention accordingly provides an inverter for
5 feeding a consuming device having an inductive component, wherein two transistors are connected in series between direct voltage terminals of the inverter and, in operation of the inverter, are controlled by first and second windings of a transformer so that they are rendered conductive
10 alternately , two free-running diodes being connected in parallel with the transistors and a tapping between the diodes, from which the output voltage of the inverter is derived, being connected with a tapping between the series connected current paths
15 of said transistors via a third winding of the transformer, and wherein the transformer comprises a fourth winding that lies in series with the first or second winding, the mid point of said series connection of transformer windings being connected to one side of the Source/Drain
20 path of a field effect transistor and the two ends thereof being connected, respectively, via two further diodes, to the other side of said path, and the said output voltage being applied to a gate electrode of said field effect transistor via a control circuit acting a pulse former.

25 Advantageous further developments of the invention will become apparent from the following description, taken in conjunction with the subordinate claims.

Several advantages result from the solution according to the invention. No separate stage is needed
30 for the control and commutation of the two transistors

because the control is effected by the transformer containing the control windings, through its magnetic energy itself. Therefore apart from the feeding of energy into the power transistors, no additional energy has to be supplied externally for their control. The said transformer does not need to be particularly accurate in construction. As a result of the invention, a self-commutating system is provided wherein the energy for the control of the transistors is derived from the alternating voltage produced by the inverter. Since the two transistors automatically cut one another off through the use of their currents, assurance is provided that the switching over of the two transistors in push-pull is effected satisfactorily. The circuit may be self-oscillating in construction. In this case, the frequency of the alternating voltage produced can be varied for adaptation to different consuming devices. In addition, the duty cycle of the alternating voltage produced can also be varied so as to vary the mean value of this alternating voltage as a result, for adaptation to different consuming devices.

The invention is illustrated by way of example in the accompanying drawings, in which:

Figure 1 shows a circuit example of the inverter according to the invention,

Figure 2 shows curves to explain the mode of operation of the circuit shown in Figure 1,

Figure 3 shows the realization of a circuit detail

from Figure 1,

Figure 4 shows the equivalent-circuit diagram for the transformer used in Figure 1,

Figure 5 shows curves to explain the equivalent-circuit diagram of Figure 4,

Figure 6 shows an example of a practical embodiment of the control circuit used in Figure 1 and

Figure 7 shows curves to explain the control circuit as shown in Figure 6. In this case, the lower-case letters show at which points of the circuits, the voltages and currents according to the graphs appear.

In Figure 1, a so-called half-bridge circuit with two transistors T1, T2 is connected between the operating voltage +B and earth. The operating direct voltage +B may be a rectified mains voltage or may be taken from an accumulator. Connected to the base-emitter paths of the transistors T1, T2 are two control windings S2 and S3 of the transformer TR1. Associated with the transistors T1, T2 are diodes D1, D2 which are designated hereinafter as free-running diodes. Connected in parallel to the diodes are capacitors C1, C2 which limit the steepness of the alternating voltage U_s produced at the terminal a. In known circuits, the connection point i of the diodes D1, D2 is connected directly to the connection point h of the transistors T1, T2. In the circuit shown in Figure 1, however, these two connection points are separated. The connected point i is connected to the connection point h via the auxiliary

winding S1. The alternating voltage U_s produced at the terminal a is supplied to the consuming device V having the inductive component L and produces an alternating current I_s for the consuming device V. The output a is connected to the control terminal r of the control circuit Cd1. The control circuit Cd1 periodically controls the V-MOS transistor T3. The transistor T3 periodically short-circuits the windings S3 and S4 via the diodes D3, D4 and initiates the switching over between the transistors T1, T2. By this means, the circuit is made self-oscillating.

The winding S1, which is additionally introduced, has the following purpose. If the transistor T1 is conducting and so the transistor T2 is cut off, the collector current i_{T1} flows via the winding S1 to the terminal a. In this case, the transformer TR1 acts as a current transformer so that the current i_{T1} through the winding S1 produces a current in the winding S2, which current is supplied to the transistor T1 as a base current i_{B1} . As a result of suitable selection of the turns ratio between the windings S1 and S2 and their poling, taking into consideration the current amplification factor β of the transistor T1, it is possible to arrange that the current i_{T1} produces the required base current i_{B1} for the transistor T1. In this case, the current i_{B1} is proportional to the current i_{T1} as desired so that as the current i_{T1} rises, the base current i_{B1} rises also. As a result of this base

current adapted to the collected current, no separate power is needed for the control. Thus the current i_{T1} is utilized, in an advantageous manner, to produce the necessary base current i_{B1} by using the current transformation caused by the transformer TR1. The base current necessary to control the transistors is obtained from the magnetic energy of the transformer. Equally, the current i_{T1} produces a current in the winding S3 through the winding S1. Since the winding S3 is oppositely poled to the winding S2, however, the transistor T2 is not controlled so as to be conducting by this current, but is held cut off.

If the transistor T1 is cut off and the transistor T2 is conducting, the collector current i_{T2} of the transistor T2 likewise flows through the winding S1 but in the opposite direction i_{T1} . Since the winding S3 is oppositely poled to the winding S2, however, the same mode of operation applies for the control of the transistor T2 by the collector current i_{T2} as for the transistor T1.

A starting circuit St is connected to the base of the transistor T2. This serves to control the transistor T2 into saturation with a pulse when the circuit is taken into service so that the whole circuit starts to oscillate. During operation of the circuit, the starting circuit St is inactive because then the circuit works in a self-oscillating manner.

The mode of operation of the circuit shown in

Figure 1 is explained in more detail with reference to Figure 2. At the moment t_1 , the transistor T3 is controlled by the control circuit Cd1 so that the voltage U_c appears at its control electrode (gate), which renders it conducting. As a result, the windings S3, S4 are short-circuited via the diodes D3, D4 and the transistor T3. The whole transformer TR1 then works in short-circuit so that practically no voltages are produced at any of the windings. The voltage U_{S3} at the winding S3 therefore breaks down to zero. As a result of the depletion time, the transistor T2, which was hitherto conducting, becomes non-conducting with a certain delay so that at the moment t_2 , the current i_{T2} drops to zero. The capacitor C_2 is then no longer short circuited by the transistor T2. As a result, the voltage U_s at the point a can rise to the value $+E$ because of the charging of the capacitor C_2 via the inductive component L of the load V . From t_2 to t_3 , a current also flows across the capacitor C_1 which charges it oscillatingly. At the moment t_3 , the diode D1 then becomes conducting so that the current i_{D1} flows up to the moment t_4 and no interruption of the current I_s occurs. The current i_{D1} is possible because the load V contains the inductive component L . At the moment t_4 , the current i_{D1} become equal to zero. Since there is now no longer any other current path, the current I_s becomes = zero at the moment t_4 . At this moment the reversal of direction of the

current I_s is effected. At the moment t_4 , the transistor T1 becomes conducting so that now the flow of current I_s begins in the opposite direction. During this time, the transistor T2 is cut off by the voltage U_{S3} . At the moment t_5 , the voltage U_c appears again at the control electrode of the FET T_3 and brings about the short-circuit operation of the transformer TR1. As a result, the base control of the transistor T1 is lost. Therefore, the current i_{T1} becomes equal to zero with a certain delay at the moment t_6 . The taking over of the current is effected for the time being by the capacitors C_1 , C_2 of which the first is charged to $+8$ and the second is charged up to the moment t_7 . At the moment t_7 , the diode D2 takes over the current i_{D2} which has dropped to zero at the moment t_9 . At this moment, the transistor T2 is turned on again by the voltage U_{S3} , as a result of which the current i_{T2} begins to flow again. The moment t_{10} corresponds to the moment t_2 .

Also connected between the windings S2 and S3 and the bases of the transistors T1, T2 are two voltage sources E1 and E2 which are poled in the cut-off direction of the transistors T1, T2. These voltage sources have the following purpose. When the FET T3 is rendered conducting by the voltage U_c the windings S3, S4 are also not completely short-circuited because of the forward voltage of the diodes D3,

D4, so that even in short-circuit operation, small voltages in the forward direction of the transistors T1, T2 appear at the windings S2, S3. the voltage sources E1 and E2 serve to accelerate the necessary turning
5 off of the transistors T1, T2.

Figure 3 shows a circuit with which the voltage sources E1, E2 can be realized. The circuit consists of two diodes D5, D6 and a capacitor C3 in each case. This has so large a capacitance that the voltage at
10 the terminals e and m remains constant and forms the required additional bias acting in the cut-off direction.

Figure 4 shows the equivalent-circuit diagram of the transformer TR1 for further explanation of the
15 control by the transistor T3. L3 is the stray inductance of the transformer TR1, seen from the side of the winding S3. The energy stored in the core of the transformer TR1 is represented by the magnetizing current i_{L3} .

20 Figure 5 shows, in principle, the control voltages for the control of the transistor T2. From t_1 to t_2 , the current i_{L3} is negative and remains constant because V_{L3} is approximately zero. The current i_{L3} flows via the diode D3 and the transistor T3.

25 From t_3 to t_4 , the current is negative. The diode D2 is conducting. The current i_{T2} is approximately zero. The current i flows via the diode D2. The current i_{L3} is substantially equal to the current i_{B2}

which prepares the conducting phase of the transistor T2 before it changes its direction. At the moment t_4 , the current changes its direction, the diode D2 is blocked and i_{T2} becomes equal to i_s . The secondary current i_{T2}/n (n approximately 6) increases the base current i_{B2} , in order to maintain the saturation of the transistor T2. At the same time, the base/emitter voltage U_{BE} of the transistor T2 rises by about 1 V as a result of which the increase in the current i_{L3} is magnified. The current i_{L3} is therefore closed via the voltage source E2 and the base/collector path of the transistor T2.

During the conducting time of the transistor T2, that is to say from t_4 - t_6 , the current i_{L3} passes through the zero value. With a sinusoidal curve, this corresponds to a phase displacement of 90° between the voltage and the current in an inductance.

Then, at the end of the conducting phase of the transistor T2, the current i_{L3} becomes positive and is drawn off by the current i_{T2}/n to form the current i_b according to Figure 5.

From t_5 - t_6 , the conducting phase of the transistor T3 and of the diode D3 causes a rapid drop in the current i_{B2} and the cutting off of the transistor T2 after the so-called depletion time.

From t_6 or t'_1 to t'_3 , the current i_{L3} has a positive direction and therefore no longer corresponds to a conducting phase of the transistor T2 but to a conducting phase of the transistor T1. The following period
5 from t'_1 to t'_5 corresponds to the conducting phase of the transistor T1 on the same principle as for the transistor T2 from T1 to t_5 . At the end of the conducting phase of the transistor T1, the current i_{L3} again becomes negative and causes the conducting phase of
10 the transistor T2. In this manner, the two transistors T1 and T2 are alternately controlled so as to be conducting and cut off.

The inductance L_3 is above a minimum value which is dependent on the amplification of the transistor,
15 on the frequency and on the voltage ($V_{C2} + U_{BE}$).

From this it follows that the current of the diode D2, which is generally considerably greater than the current i_{L3} , should not flow through the primary winding
S1 of the transformer TR1. To high a value of the
20 current $i_{T2/n}$ from $t_1 - t_3$ would prevent the current i_{B2} so that the transistor T2 would not be able to become conducting. Then the circuit would not work satisfactorily.

The constructions and mode of operation of the
25 control circuit Cd1 are described with reference to Figures 6, 7. The control circuit Cd1 serves to control the transistor T3 and so to control the particular conducting phase of each transistor T1, T2. The output

voltage U_s from the point a in Figure 1 is applied to the input terminal x of the control circuit Cd1. The operating voltage +8 is stabilized by the diode D9 and limited to a value of about +12V. At the point s, the voltage U_s is clamped to zero by the diode D7. Thus, as a result of the action of the capacitor C3 and of the resistor R1 there is a voltage at the point s, the amplitude of which is not dependent on the amplitude of the voltage U_s . The resistor R4 and the capacitor C4 form an integrating network for the voltage U_1 .

As a result, the sawtooth voltage U_s appears at the point t. The threshold-value circuit with the transistors T4 and T5 has two threshold values which are determined by the voltage sources U_3 and U_4 and with which the voltage U_2 is compared. The voltage source U_4 forms the lower threshold value U_{w1} via the transistor T4 and the sum voltage U_3+U_4 forms the upper threshold value U_{w2} via the transistor T5. If the voltage U_s has its lower value, the voltage U_1 is equal to zero. Therefore the voltage U_2 drops and, at the moment t_1 , drops below the lower threshold value U_{w1} . As a result, the transistor T4 becomes conducting and controls the transistors T6 and T3 so that they become conducting. As a result, the voltage U_c , which is also represented in Figures 1, appears at the control electrode (gate) of the transistor T3 and renders it conducting.

After the delayed switching over of the power stage

according to Figure 1, the voltage U_s again rises and reaches the operating voltage $+8$. The current via the capacitor C_3 and the resistor R_1 , which is now reversed, is somewhat greater than the current through the resistor R_4 so that the diode D_8 now becomes conducting. The voltage U_1 goes rapidly up to the operating voltage of $+12$ V and produces a rising voltage U_2 . The transistors T_6 and T_3 are only cut off when the voltage U_s has reached the operating voltage $+8$.

At the moment t_5 , the voltage U_2 exceeds the upper threshold value U_{w2} . The transistors T_5 , T_7 , T_6 and T_3 remain conducting so long as the voltage U_s has not become zero. In a corresponding symmetrical manner, the voltage U_1 becomes equal to zero during the descending edge of the voltage U_s , the voltage U_2 drops and the complete operation is repeated. With a given RC network, the frequency depends on the difference between the upper threshold value and the lower one. The duty cycle of the output voltage U_s is dependent on the mean value between the upper threshold value and the lower one. If this is equal to half the operating voltage $+8$ of the control circuit Cd_1 , the duty cycle is equal to $1/2$.

Thus, in Figure 1, the control circuit Cd_1 can be influenced at the terminal t so that the frequency of the voltage U_s or its duty cycle and hence its effective value varies. This can be effected by altering the voltage sources U_3 and U_4 .

Thus, in principle, the circuit shown in Figure 6 contains an amplitude limiter with the diodes D8 and D7 for the voltage U_s , and RC network $R4/C4$ causing a timing, a threshold-value circuit with the transistors T4, T5 and the voltage sources U3, U4, and a control circuit with the transistors T6, T7 to control the transistor T3 which, in Figure 1, serves as a switch to short-circuit the winding S3. The capacitors C1, C2 in Figure 1 limit the steepness of the alternating the voltage U_s produced. In Figure 1, these capacitors may also be connected directly in parallel with the collector-emitter paths of the transistors T1, T2.

CLAIMS

1. An inverter for feeding a consuming device having an inductive component, wherein two transistors are connected in series between direct voltage terminals of the inverter and, in operation of the inverter, are controlled by first and second windings of a transformer so that they are rendered conductive alternately , two free-running diodes being connected in parallel with the transistors and a tapping between the diodes, from which the output voltage of the inverter is derived, being connected with a tapping between the series connected current paths of said transistors via a third winding of the transformer, and wherein the transformer comprises a fourth winding that lies in series with the first or second winding, the mid point of said series connection of transformer windings being connected to one side of the Source/Drain path of a field effect transistor and the two ends thereof being connected, respectively, via two further diodes, to the other side of said path, and the said output voltage being applied to a gate electrode of said field effect transistor via a control circuit acting a pulse former.
2. An inverter as claimed in Claim 1, wherein the control circuit comprises a voltage limiter, a time-constant network and a threshold-value circuit.
3. An inverter as claimed in Claim 2, wherein the threshold-value circuit has two threshold values.





4. An inverter as claimed in Claim 3, wherein the threshold values are adjustable to vary the frequency and the duty cycle of the output voltage of the inverter.
5. An inverter substantially as described herein with reference to Figures 1 to 5, or Figures 1 to 7 of the accompanying drawings.
-

