Jan. 4, 1944. H. KLEMPERER 2,338,118

INVERTER

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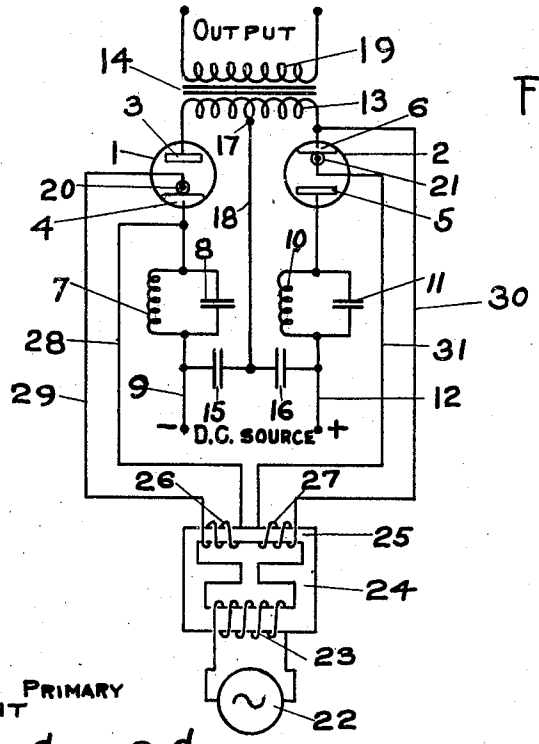


FIG. 1.

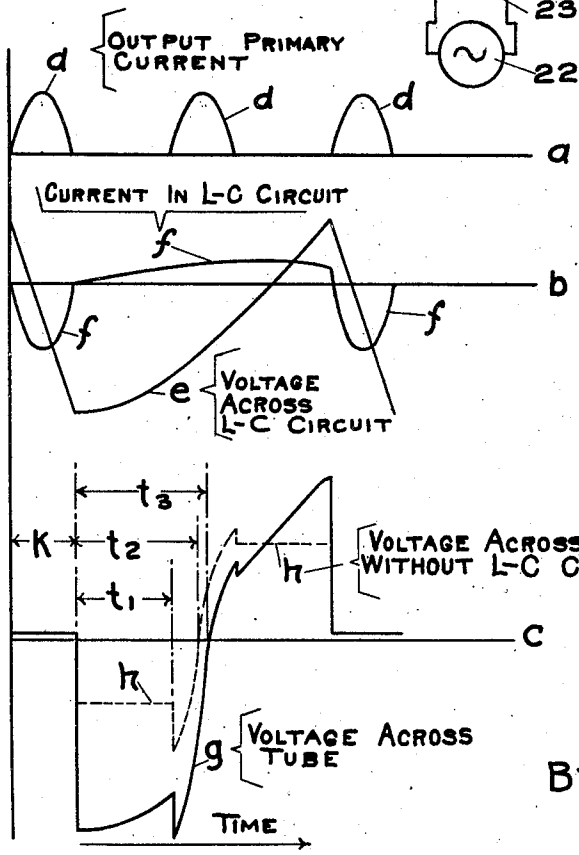


FIG. 2.

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FIG. 3.

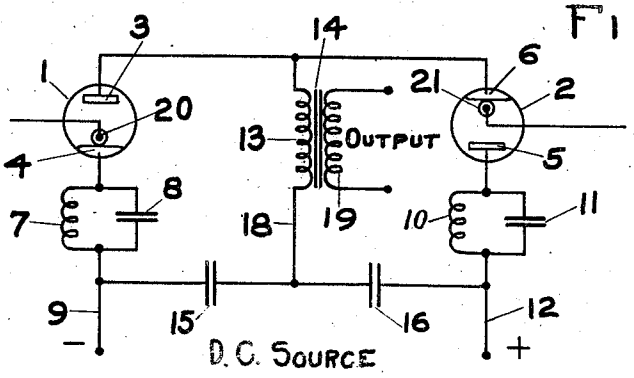


FIG. 4.

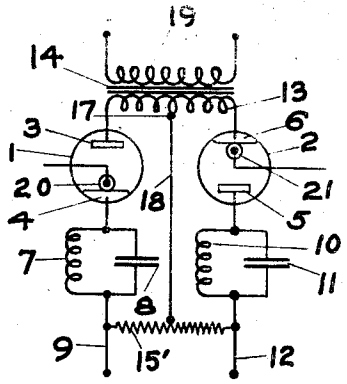
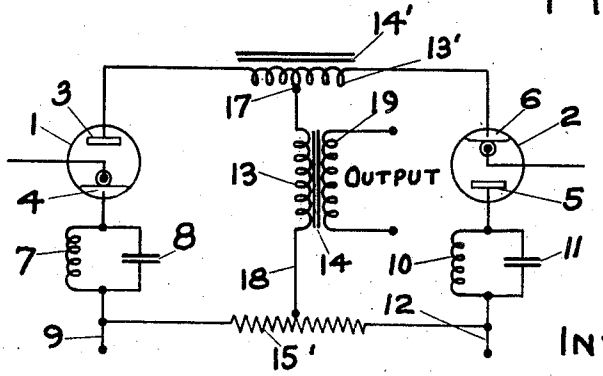


FIG. 5.



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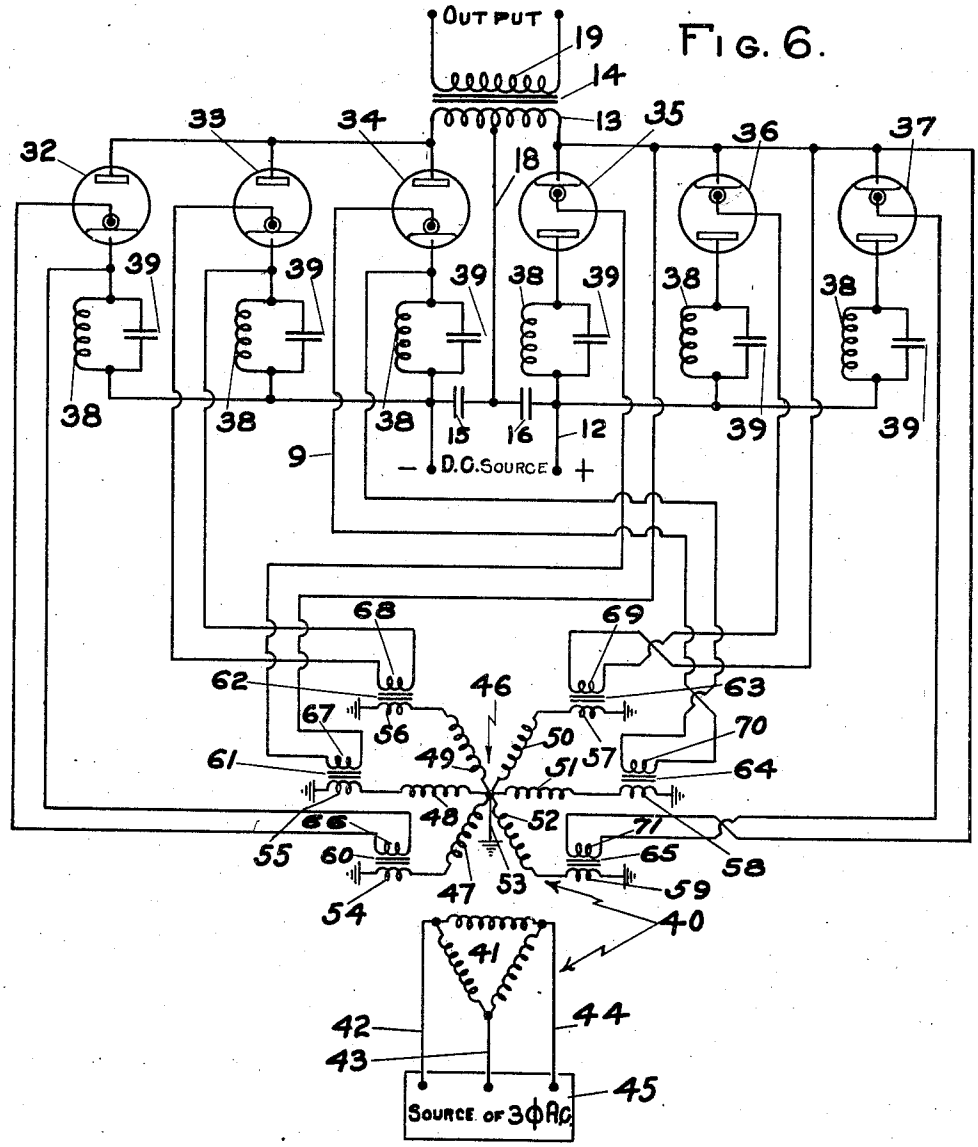


FIG. 6.

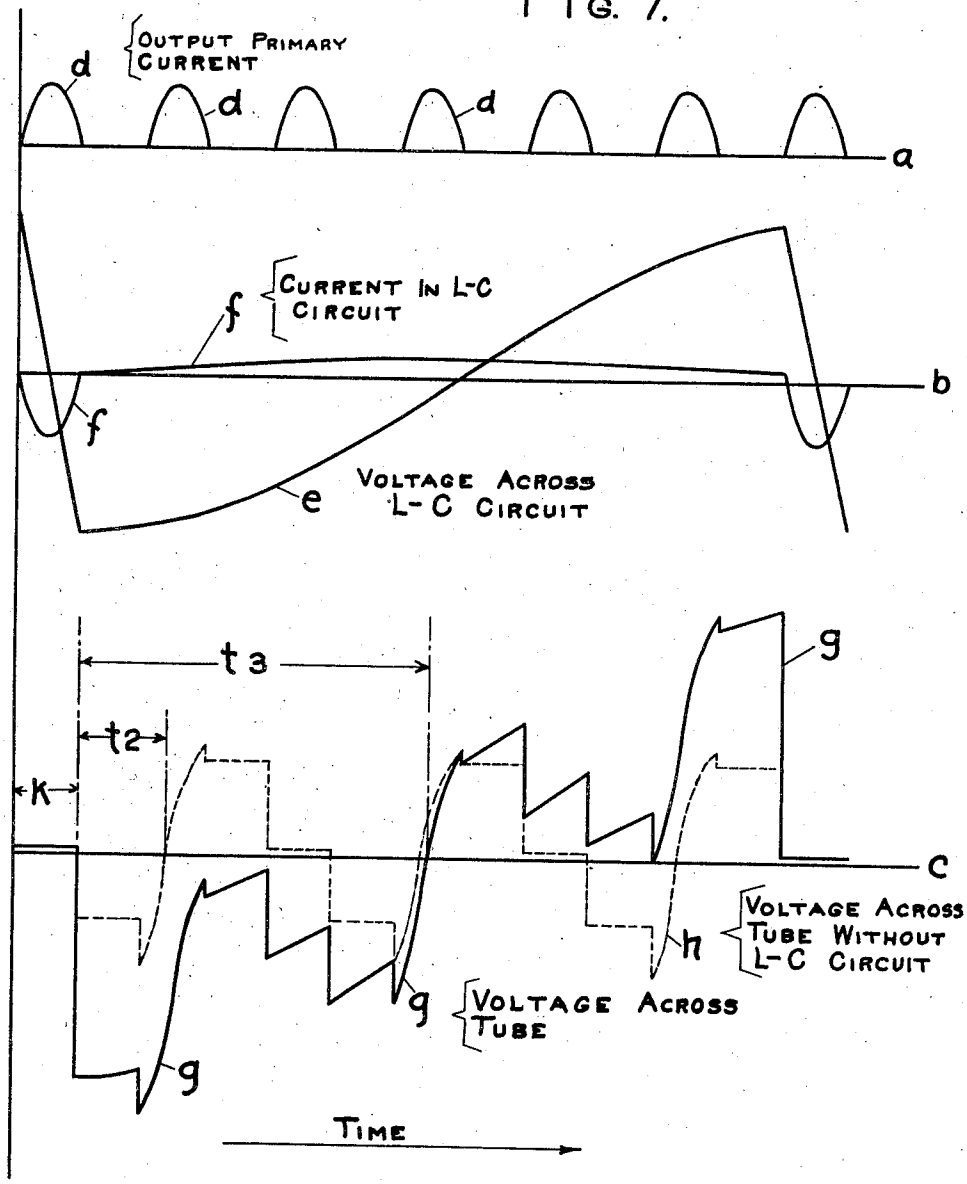
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FIG. 7.



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Patented Jan. 4, 1944 2,338,118

UNITED STATES PATENT OFFICE

2,338,118

INVERTER

Hans Klemperer, Belmont, Mass., assignor to Raytheon Manufacturing Company, Newton, Mass., a corporation of Delaware

Application August 6, 1940, Serial No. 351,630

18 Claims. (Cl. 175—363)

This invention relates to inverters of the series type utilizing controlled gas filled electrical discharge tubes for converting direct current into alternating current.

Heretofore when it was attempted to increase the frequency or the power handled by such converters, failure has occurred due to the fact that an insufficient de-ionization time was available for each tube and therefore control of the tube was destroyed.

An object of this invention is to increase the reliability of operation of inverters of the foregoing type so that de-ionization and consequent protection of the system against short circuiting the direct current source is reliably secured.

Another object of this invention is to increase both power and the frequency which such inverters are capable of handling.

A further object is to devise an arrangement in which the forward voltage on each tube is increased when conduction is desired but is decreased when non-conduction is desired.

A still further object is to increase the inductance in series with the direct current source so as to limit the rate of rise of short circuit direct currents without, at the same time, substantially increasing the impedance of the system to alternating currents of the output frequency.

The foregoing and other objects of this invention will be best understood from the following description of exemplifications thereof, reference being had to the accompanying drawings wherein:

Fig. 1 is a diagrammatic representation of an inverter system embodying my invention;

Fig. 2 is a set of curves illustrating the mode of operation of the arrangement shown in Fig. 1;

Figs. 3, 4, and 5 are diagrams of modifications of the arrangement shown in Fig. 1;

Fig. 6 is a diagram of an embodiment of my invention utilizing a larger number of tubes and capable of greater power and higher frequency operation; and

Fig. 7 is a set of curves illustrating the mode of operation of the arrangement shown in Fig. 6.

The inverter illustrated in Fig. 1 consists of a pair of controlled discharge tubes 1 and 2. These are preferably gas filled tubes of the controlled ignition type. Tube 1 contains an anode 3 and a cathode 4, preferably of the mercury pool type. The tube 2 likewise contains an anode 5 and a cathode 6 which preferably is similar to cathode 4. An inductance 7 in parallel with a condenser 8 is connected from the cathode 4 to a conductor 9 which extends to the negative terminal of some suitable direct current source. Likewise, an inductance 10 in parallel with a condenser 11 is connected from the anode 5 to a conductor 12 which extends to the positive side of the direct current source. The anode 3 and the cathode 6 are connected to the ends of the primary winding 13 on an output transformer 14 having a secondary winding 19 which is adapted to be connected to some suitable output device. A pair of condensers 15 and 16 are connected in series between the conductors 9 and 12. The primary winding 13 is provided with a center tap 17 from which a conductor 18 is connected to a point intermediate the condensers 15 and 16.

The tubes 1 and 2 are provided with suitable igniting electrode elements 20 and 21 for the cathodes 4 and 6 respectively. Although these igniters are of any suitable kind, they preferably are of the electrostatic type as described and claimed in the co-pending application of Percy L. Spencer, Serial No. 303,963, filed November 13, 1939. Such igniters are generally a conductor separated and insulated from the cathode pool by a thin glass layer. In order to supply igniting impulses to the igniters 20 and 21, a source of alternating current 22 is connected to the primary winding 23 of a peaking transformer 24 having a saturable leg 25 which carries a pair of secondary windings 26 and 27 in which peaked igniting voltages are generated. A pair of conductors 28 and 29 connect the secondary winding 26 between the cathode 4 and its associated igniter 20. A pair of conductors 30 and 31 connect the secondary winding 27 between the cathode 6 and its associated igniter 21.

When the system described above is energized, the condensers 15 and 16 are each charged to a voltage which is approximately half the voltage of the direct current source connected between the conductors 9 and 12. Thereupon the secondary winding 26, for example, supplies an igniting impulse to the igniter 20 which starts an arc spot on the cathode 4 and permits the tube 1 to conduct current. The condenser 15 having been charged to a direct current voltage as described above makes the anode 3 positive with respect to the cathode 4 and therefore causes the tube 1 to conduct a pulse of current which discharges the condenser 15. The discharge circuit of the condenser 15 may not be critically damped and therefore its discharge current may tend to be oscillatory. Therefore, when the condenser 15 discharges through the tube 1, its voltage is reversed and the magnitude of the reversed voltage is determined by the degree to which energy is

absorbed in the output circuit. Since the voltage which is impressed upon the condenser 16 is the sum of the direct current source of voltage and the voltage on the condenser 15, it will be seen that during the discharge of the condenser 15, the condenser 16 is charged to a somewhat higher potential than that of the direct current source.

The discharge current for the condenser 15 and the charging current for the condenser 16 flows primarily through the condenser 8 due to the fact that the inductance 7 offers a relatively high impedance to such currents. Therefore the condenser 8 likewise is charged to a voltage which makes its upper end positive and its lower end negative. It will be seen likewise that the charge on the condenser 16 is such that its left end is negative and its right end is positive. The voltage on the condenser 16 substantially neutralizes the voltage of the direct current source so as to tend to extinguish the tube 1. In addition, the voltage on the condenser 8 is in a direction so as to extinguish the tube 1. The result, therefore, is that when the condenser 15 is discharged the condensers 8 and 16 extinguish the flow of current in the tube 1. The foregoing operation causes a short pulse of current to flow from the center tap 17 through the left half of the primary winding 13. At some later time, the secondary winding 27 supplies an igniting impulse to the igniter 21 which causes the tube 2 to fire. Current now flows in such a direction as to discharge the condenser 16 and charge the condenser 15 to a higher voltage than it initially had, in a manner similar to that described in connection with the initial discharge of condenser 15. In this case also, the discharge current for condenser 16 and the charging current for the condenser 15 flows primarily through the condenser 11 and the charge on the condensers 11 and 15 extinguishes the discharge in the tube 2. This action likewise causes a short pulse of current to flow to the center tap 17 through the right half of the primary winding 13.

The flowing of current pulses through each half of the primary winding 13 introduces an additional commutating action into the system. When tube 1, for example, is fired so as to produce a pulse of current flowing from the center tap 17 through the left half of the primary winding 13, a back voltage is generated opposing such flow of current. This back voltage is likewise generated in the right half of the primary winding 13 and is in the non-conducting direction of tube 2. If at this time, there is any tendecy for tube 2 to conduct current in the forward direction, the voltage impulses thus generated cause such tendency to be extinguished.

In absence of the parallel circuits comprising the inductance 7 and the condenser 8, and the inductance 10 and condenser 11, shortly after the starting of either tube 1 or 2, a relatively high forward voltage would be impressed on the opposite tube. This would occur within a very short time interval after conduction in said opposite tube ceases. This time interval would be decreased as the frequency would increase. In the present invention, however, the charges on the condensers 8 and 11 respectively do not immediately disappear inasmuch as they can only be reversed through the inductances 7 and 10 respectively. Therefore, the voltages on these condensers 8 and 11 remain as voltages in opposition to the forward voltage applied to the associated tubes following the starting of the opposite tube. The effect, therefore, is to delay the application of the forward voltage to the tubes 1 and 2 and thus give them a longer time in which to de-ionize. The frequency of the parallel inductance and capacity circuits is not critical, but the maximum effect is produced when the frequency of each of these circuits equals the frequency of firing of the associated tube. Under these conditions, when the time arises for either tube 1 or 2 to fire, the charge on the associated condensers 8 or 11 will have reversed and thus be in a direction to assist the tube to fire. Part of the energy which is stored in the charge on the condenser will, under these conditions, be delivered as useful energy to the output system by the current flowing through the primary winding 13 and due to the fact that the discharge circuit for such condensers contains considerable inductance, part of the energy will be returned to the condenser to charge it in the opposite direction so as to assist in the de-ionization of its associated tube.

The foregoing operation may be more clearly understood from the curves of Fig. 2. Along axis *a* are shown a series of current pulses *d* representing the current pulses delivered to the primary winding 13. The left hand current pulse may, for example, be delivered as a result of the firing of tube 1. A substantially similar pulse of current *f* shown on the *b* axis is delivered to the condenser 8. Said condenser, prior to this time, has acquired a certain charge as will be pointed out below. When the pulse of current *f* is delivered to the condenser, it neutralizes the previous charge and causes the condenser to be charged up in the opposite direction to a somewhat higher potential. Along the axis *c*, the time during which the left pulse of current *d* flows is represented as *k*. During this time, the tube is conducting and its voltage, represented by *g* remains substantially constant at the voltage drop of said tube. At the end of the time *k* the current *d* which is likewise flowing through the tube, tends to reverse and since the tube cannot conduct such reversed current, it stops conducting. In absence of the inductance 7 and condenser 8, when tube 1 stops conducting current, the reversed voltage of the condenser 15 would appear across it. This voltage is represented by the lower horizontal portion of the dotted curve *h* on the axis *c*. In the arrangement as shown in Fig. 1, however, in addition to the reversed voltage of the condenser 15, the voltage on the condenser 8 is likewise impressed on the tube 1 in the non-conducting direction, so that the voltage which appears across the tube 1 in the non-conducting direction at the end of the time *k* is the sum of these two voltages as stated above. Since the back voltage is increased to this extent, the ions are swept out of the discharge space at a more rapid rate and de-ionization is accelerated.

After the time *k* the condenser 8 starts to discharge through the inductance 7 at a rate determined by the natural frequency of the parallel inductance-capacity circuit as shown on the axis *b* in Fig. 2. In the arrangement as shown in Fig. 1, the natural frequency of the parallel inductance-capacity circuit is somewhat lower than the output frequency of the system. Due to the discharge current flowing from the condenser 8, its voltage will decrease along the curve *e*, reverse in direction, and acquire a certain value in the opposite direction. When the associated tube is again fired, the voltage which would appear

across the tube 1 in absence of the inductance-capacity circut represented by the dotted curve *h* after the time *k*, continues at the value of the reversed voltage on the condenser 15 for a time t_1 when the tube 2 is fired. Due to the back voltage generated in the primary winding 13 as pointed out above, an increased inverse voltage would be impressed on the tube 1 causing the lower peak to occur on the curve *h*. Due to the firing of the tube 2 the next pulse of current *d* is supplied to the primary winding 13. During this time, under the conditions of operation, in absence of the parallel inductance-capacity circuit, the discharge and reversal of voltage of the condenser 16 would cause the voltage across the tube 1 to decrease, reverse, and increase in the opposite direction as shown by the dotted curve *h*. Since each tube is not extinguished exactly at the zero value of current but at a value slightly above it, a back voltage generated in the primary winding 13 upon the termination of the current flow in the tube 2 causes a slight decrease in the value to which the condenser 15 is charged during the discharge and reversal of voltage on the condenser 16. This produces the drop in the curve *h* from its upper peak value as shown in Fig. 2. Thereupon the voltage across the tube 1 would conduct along the upper horizontal value of the curve *h* which likewise represents the value of the voltage acquired by the condenser 15. Since, as pointed out above, the resultant voltage on the tube 1 in the arrangement shown in Fig. 1 is the summation of the voltage across the inductance-capacity circuit and the voltage which would appear across the tube in absence of said circuit, this resultant voltage may be represented in Fig. 2 by the summation of the curves *e* and *h*. In Fig. 2, curve *g* after the time *k* represents this summation. It will be seen by the curves on the axis *c* that without the inductance-capacity circuit, the voltage across tube 1 remains in the non-conducting direction following the stoppage of conduction in said tube for the time t_2. However, due to the delay in the reversal of this voltage by the inductance-capacity circuit, in the present arrangement, the voltage thus remains in the non-conducting direction for a longer time t_3. The time during which the voltage remains in the non-conducting direction is the de-ionization time of the tube, and therefore, it will be seen that by the present arrangement the de-ionization time of each tube can be decreased. Furthermore, it will be noted that when the voltage on the tube 1 does reverse, it does not increase at as rapid rate as that which would occur in absence of the parallel inductance-capacity circuit. Since the tendency of this type of tube to break down before being supplied with an igniting impulse depends to a large degree on the rapidity at which the forward voltage is applied thereto, this decrease in the rate at which the forward voltage is applied increases the reliability of operation and decreases the tendency for premature firing to occur. It will further be seen that when the time comes for the tube 1 to again be fired to supply the third pulse of current *d*, its forward voltage is the voltage of the condenser 8 as well as that of the condenser 15 so that the forward voltage on said tube is increased to a substantial extent. This increase in the forward voltage tends to make the firing of the tube more reliable and also tends to increase the amount of power which may be handled by the system.

From the above, it will be seen that three substantially independent commutating means are present in the arrangement shown in Fig. 1. These are the two condensers 15 and 16, the primary winding 13 acting through its back E. M. F. on each of the tubes, and the parallel inductance-capacity circuits associated with the two tubes. This makes for a very reliable type of operation.

In some instances, however, one of the foregoing commutating means may be dispensed with and satisfactory operation obtained. For example, Fig. 3 shows an arrangement in which the commutating effect of the center tapped primary winding 13 of Fig. 1 is eliminated by placing said primary winding directly in series with the conductor 18 extending to a point intermediate the condensers 15 and 16. In Fig. 3 where the elements are identical with those shown in Fig. 1, the same reference numerals are applied. Fig. 3 operates in the same way as described in connection with Fig. 1 except that the commutating effect of the center tapped primary winding 13 of Fig. 1 is eliminated. It will be noted that in Fig. 3, instead of taking the output energy from the upper connection between the two tubes as shown in Fig. 1, the output energy is taken from the central connection. Under these conditions, instead of the pulses of output current being delivered successively in the same direction as in the case of Fig. 1, such pulses are delivered successively in opposite directions in Fig. 3.

Fig. 4 shows an additional modification of Fig. 1 in which the commutating effects of the condensers 15 and 16 are eliminated. In Fig. 4 likewise, where the elements are identical with those of Fig. 1 the same reference numerals are applied. In Fig. 4 the series connection of the two condensers 15 and 16 of Fig. 1 is replaced by a voltage dividing resistance 15'. The arrangement shown in Fig. 4 operates in a manner similar to that described in connection with Fig. 1 except that the commutating effects of condensers 15 and 16 are eliminated and the energy for commutating each tube is stored primarily in the condensers 8 and 11, respectively.

If it is desired to take off the output energy from the central connection as shown in Fig. 3 and at the same time utilize the commutating effects of a center tapped coil connected between the two tubes, the arrangement shown in Fig. 5 may be utilized. In this figure a voltage dividing resistance or inductance 15' is used as in Fig. 4 instead of the condensers 15 and 16 of Fig. 1. The primary winding 13 is arranged in series with the central conductor 18 as in Fig. 3. In addition, an induction coil 13' is connected between the anode 3 and the cathode 6. This coil is wound upon a suitable magnetic core 14'. The center tap 17 in this instance is on the coil 13'. In Fig. 5 the system operates in a manner similar to that of Fig. 4 differing therefrom in the output current impulses in the same way as Fig. 3 differs from Fig. 1.

If it is desired to increase either the power or the frequency of the inverter over that which is practical for the foregoing embodiments, a system utilizing a larger number of tubes may be used. Such an arrangement is shown in Fig. 6. Here also where the elements are identical with those in Fig. 1, the same reference numerals are applied. Instead of using two tubes as in Fig. 1, however, a plurality of pairs of tubes 32, 33, 34, 35, 36, and 37 are provided. Each of these tubes is preferably similar to the tubes 1 and 2 of Fig. 1 and are therefore provided with an anode, pool type cathode, and an igniting electrode element.

The tubes 32, 33, and 34 have their anodes connected to one side of the primary winding 13 while the tubes 35, 36, and 37 have their cathodes connected to the right end of said primary winding in a manner similar to that described in connection with tubes 1 and 2 of Fig. 1. In Fig. 6, each of the tubes has connected in series therewith a parallel inductance-capacity circuit consisting of an inductance 38 and a capacitor 39. Each of the igniting electrode elements is supplied with igniting impulses from an igniting transformer 40, having a primary winding 41 preferably connected in delta. Said primary winding is connected through leads 42, 43 and 44 to a suitable source of three phase alternating current 45. The igniting transformer 40 is provided with a six phase secondary winding 46 connected in star. The secondary winding 46 consists of secondary coils 47 to 52 inclusive. The neutral point of the secondary winding 46 is provided with a ground connection 53. In series between the outer ends of the secondary coils 47 to 52 inclusive and ground, are connected primary windings 54 to 59 inclusive of peaking transformers 60 to 65 inclusive. These peaking transformers are provided with secondary windings 66 to 71 inclusive. Connections are made from the peaking transformers to the tubes so that the tubes on opposite sides of the inverters are alternately fired in sequence. For this purpose, the secondary windings of the peaking transformers are connected to the tubes as follows: secondary winding 66 to tube 32, secondary winding 67 to tube 35, secondary winding 68 to tube 33, secondary winding 69 to tube 36, secondary winding 70 to tube 34, and secondary winding 71 to tube 37. Each igniter of the type described above produces an arc spot on its associated cathode when it is supplied with a voltage impulse which is positive with respect to the cathode. The peaking transformers, however, each supplies pulses which are alternately opposite in polarity. As shown in Fig. 6, by reversing the connections to the secondary windings 69 to 71, each compared to the secondary windings 66 to 68, the alternate firing of tubes on opposite sides of the inverter may be produced.

The operation of the arrangement shown in Fig. 6 may be more clearly understood by referring to the curves of Fig. 7. Along axis *a* are shown a series of current pulses *d* representing pulses of current delivered to the primary winding 13. The left hand current pulses may, for example, be delivered as a result of the firing of tube 32. As described in connection with Fig. 2, during this period which is again represented by *k* a pulse of current *f* is delivered to the associated condenser 39, causing the voltage *e* of said condenser to reverse as indicated on the axis *b* of Fig. 7. Thereafter, the charge on the condenser 39 discharges through its associated inductance 38 in a pulsatory manner so that the voltage *e* of said condenser reverses, also as shown on the axis *b*, while the current in the inductance-capacity circuit varies in accordance with the curve *f*. In absence of the use of the condenser 39 and inductance 38, the voltage across each tube in the arrangement of Fig. 6 would follow the dotted curve *h* on the axis *c* of Fig. 7. However in the arrangement shown, the voltage *e* of the inductance-capacity circuit is added to said voltage *h* and the resultant voltage across each tube is represented by the summation curve *g*. From Fig. 7, it will be seen that in absence of the inductance 38 and capacity 39, the de-ionization of each tube would be represented by the relatively short time t_2 while in the arrangement of Fig. 6, the de-ionization is considerably increased to the value as represented by t_3. In order to produce the maximum effect of the parallel inductance-capacity circuit, the frequency of oscillation is selected as a sub-multiple of the output frequency so that the voltage across each of the condensers 39 completely reverses between each pulse of charging current supplied thereto. As previously stated, the frequency of this inductance-capacity circuit is not critical and may vary considerably from such a value.

Of course, it is to be understood that this invention is not limited to the particular details as described above as many equivalents will suggest themselves to those skilled in the art. For example, other types of controlled discharge tubes may be utilized as well as various other numbers of such tubes. Other variations and utilizations of principles innumerable will suggest themselves to those skilled in the art. It is accordingly desired that the appended claims be given a broad interpretation commensurate with the scope of the invention within the art.

What is claimed is:

1. An inverter comprising a space discharge tube, a commutating means and an output means in series, means for connecting said inverter to a source of voltage, and means for generating a periodic voltage tending to increase current flow through said tube during the conducting period and to oppose such flow of current during the non-conducting period following stoppage of current flow upon commutation.

2. An inverter comprising a space discharge tube, a commutating means and an output means in series, means for connecting said inverter to a source of voltage and means for generating a periodic voltage aiding the first named voltage during flow of current through said tube and opposing said first named voltage upon stoppage of current flow by said commutating means.

3. An inverter comprising a space discharge tube, a commutating means and an output means in series, means for connecting said inverter to a source of voltage, and means responsive to the initiation of current through said tube to increase the magnitude of said current and to decrease the tendency of said current to flow during the non-conducting period following stoppage of current by said commutating means.

4. An inverter comprising a space discharge tube, a commutating means, an impedance means, and an output means in series, and means for connecting said inverter to a source of voltage, said impedance means having a relatively high inductance value and a relatively low alternating current impedance value to periodic currents of substantially the output frequency of said inverter.

5. An inverter comprising a space discharge tube, a commutating means, an impedance means, and an output means in series, and means for connecting said inverter to a source of voltage, said inverter being tuned to substantially the desired output frequency, said impedance means having a relatively high inductance value and such a relatively low alternating current impedance value that said tuned frequency is substantially unimpeded by said impedance means.

6. An inverter comprising a space discharge tube, a condenser, and an output means in series, an inductance and a condenser connected in

parallel with each other in series with said tube, and means for connecting said inverter to a source of voltage.

7. An inverter comprising a space discharge tube, a condenser, and an output means in series, an inductance and a condenser connected in parallel with each other in series with said tube, means for discharging said first-named condenser, and means for connecting said inverter to a source of voltage.

8. An inverter comprising a space discharge tube, a commutating means, and an output means in series, and means for connecting said inverter to a source of voltage, said inverter having a predetermined output frequency, an inductance and a condenser connected in parallel with each other in series with said tube, said parallel circuit being tuned to a substantially lower frequency than said output frequency.

9. An inverter comprising a space discharge tube, a condenser, and an output means in series, and means for connecting said inverter to a source of voltage, said inverter having a predetermined output frequency, an inductance and a condenser connected in parallel with each other in series with said tube, said parallel circuit being tuned to a substantially lower frequency than said output frequency.

10. An inverter comprising a space discharge tube, a condenser and an output means in series, means for connecting said inverter to a source of voltage, said inverter having a predetermined output frequency, an inductance and a condenser connected in parallel with each other in series with said tube, said parallel circuit being tuned to a substantially lower frequency than said output frequency, and means for discharging said first-named condenser.

11. An inverter comprising a plurality of space discharge tube paths, a commutating means and an output means in series and a separate independent inductance and a condenser connected in parallel with each other in series with each of said paths, and means for connecting said inverter to a source of voltage.

12. An inverter comprising a plurality of space discharge tubes connected in parallel and connected in series with a commutating means, and feeding a common output means, means for connecting said inverter to a source of voltage, an independent inductance and a condenser connected in parallel with each other in series with each of said tubes and means for firing each of said tubes at a submultiple of the desired output frequency, said firing means being displaced in phase so that said tubes supply pulses of current successively to said output means.

13. An inverter comprising a plurality of space discharge tubes each connected in series with a commutating means and feeding a common output means, an independent inductance and a condenser connected in parallel with each other in series with each of said tubes and means for firing each of said tubes at a submultiple of the desired output frequency, said firing means being displaced in phase so that said tubes supply pulses of current successively to said output means.

14. An inverter comprising two condensers connected in series and adapted to be connected across a source of current, a space discharge tube feeding an output means and connected between one end of said series circuit and a point between said condensers, another space discharge tube feeding said output means and connected between the other end of said series circuit and said point, an independent inductance and a condenser connected in parallel with each other in series with each of said tubes, and means for alternately firing said tubes.

15. An inverter comprising two condensers connected in series and adapted to be connected across a source of current, a space discharge tube feeding an inductance and connected between one end of said series circuit and a point between said condensers, another space discharge tube feeding said inductance, and connected between the other end of said series circuit and said point, an independent inductance and a condenser connected in parallel with each other in series with each of said tubes, and means for alternately firing said tubes.

16. An inverter comprising two condensers connected in series and adapted to be connected across a source of current, a space discharge tube feeding a part of an inductance and connected between one end of said series circuit and a point between said condensers, another space discharge tube feeding another part of said inductance and connected between the other end of said series circuit and said point, an independent inductance and a condenser connected in parallel with each other in series with each of said tubes, and means for alternately firing said tubes.

17. An inverter comprising a resistance adapted to be connected across a source of current, a space discharge tube feeding an output means and connected between one end of said resistance and an intermediate point in said resistance, another space discharge tube feeding said output means and connected between the other end of said resistance and said point and means for alternately firing said tubes.

18. An inverter comprising a space discharge tube, a commutating means, an impedance means, and an output means in series, and means for connecting said inverter to a source of voltage, said impedance means having a relatively high impedance to frequencies substantially lower than the output frequency of said inverter, and a relatively low impedance to frequencies of substantially said output frequency or higher.

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