Aug. 19, 1924. 1,505,234

M. K. AKERS

VACUUM TUBE FREQUENCY CONVERTER

Filed Dec. 18, 1920

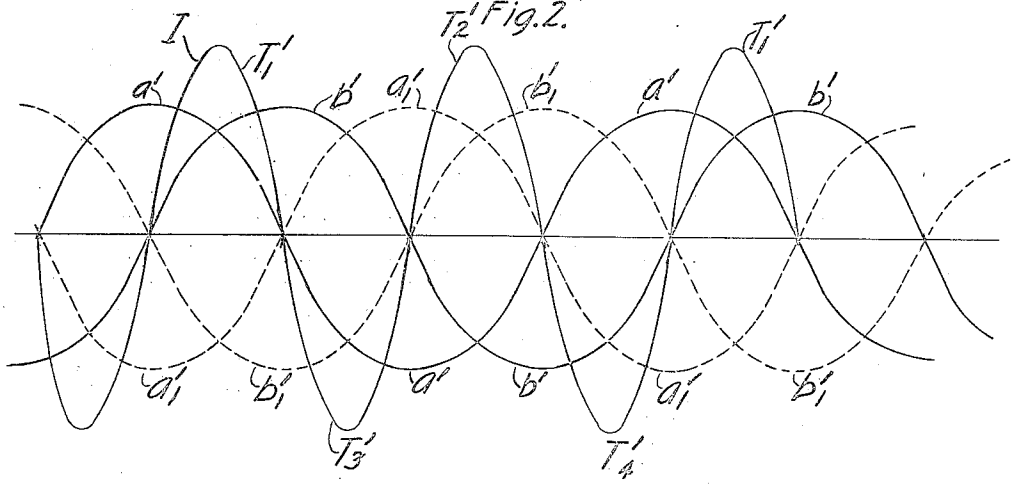
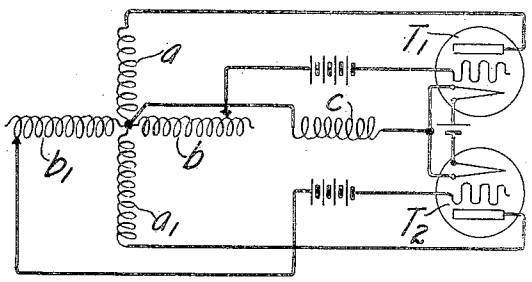


Fig. 2.

Fig. 1.



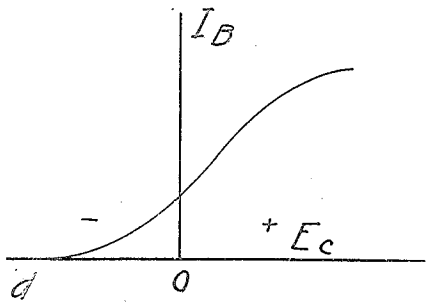
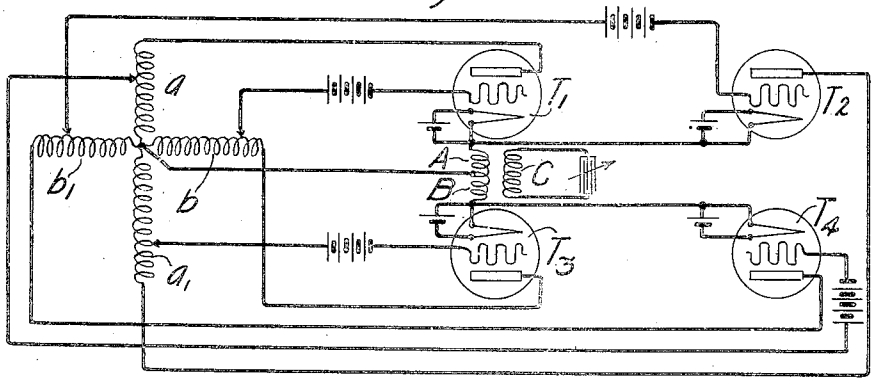


Fig. 3.

Fig. 4.



Inventor:
Milton K. Akers
by C. Cl. Sprague Att'y.

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UNITED STATES PATENT OFFICE.

MILTON K. AKERS, OF TROY, OHIO, ASSIGNOR TO WESTERN ELECTRIC COMPANY, INCORPORATED, OF NEW YORK, N. Y., A CORPORATION OF NEW YORK.

VACUUM-TUBE FREQUENCY CONVERTER.

Application filed December 18, 1920. Serial No. 431,572.

To all whom it may concern:

Be it known that I, MILTON K. AKERS, a citizen of the United States, residing at Troy, in the county of Miami, State of Ohio, have invented certain new and useful Improvements in Vacuum-Tube Frequency Converters, of which the following is a full, clear, concise, and exact description.

This invention relates to a method of and arrangement for frequency conversion and particularly to a method of changing a low frequency polyphase current to a high frequency single phase current.

The object of the invention is to provide a method of and means for frequency conversion, making use of three-electrode electric discharge devices.

A further object of the invention is to provide a method of frequency conversion making use of three-electrode electric discharge devices and in which the product of the conversion is a single multiple frequency wave having a substantially pure sine wave form.

A more specific object is to provide a system, including a three-electrode electric discharge device, in which rectified current is caused to flow during only a predetermined portion of the impressed voltage cycle, and in which, by the use of a plurality of units, the low period impulses of alternating current implied by the language above, is multiplied into a high frequency continuous wave of substantially pure sine wave form.

This invention belongs to that class of frequency converters, sometimes denominated frequency changers, characterized by a lack of moving parts. Inventions of this generic class which have heretofore been conceived are commonly modified rectifying systems in which both halves of the alternating current wave are rectified by the use of energy storing devices or by the use of multiple unit arrangements. Although several means have been employed in these systems for approximating a pure wave form, the resulting current, after transforming, is essentially an impulse current having the form of a badly distorted alternating current sine wave.

The system of the present invention as distinguished from prior systems to be described, has the merit that the resultant wave form a fundamental of the desired high frequency and accordingly that a relatively great portion of energy of the supply wave is employed to produce the desired high frequency component. In other systems of the generic class, means are provided for distorting the form of the supplied wave which may then be analyzed into its various components by means of proper circuit arrangements. Since the distorted wave has fundamentally the same frequency as the wave impressed on the system, the desired high frequency component which is capable of separation therefrom is almost necessarily of relatively small amplitude and energy content as compared with the said fundamental wave, the frequency conversion accordingly being accomplished by a degradation of the product wave with resulting low efficiency.

Since a high frequency alternating current, within practical limitations, consists of a continuous and uniform succession of sine waves each having a small period, the problem here presented is to devise a method for causing such interaction of the electrical quantities in a low frequency polyphase system through the medium of a combining device that there will result a wave having a smaller period than the period of the electrical quantities of said system, and having a substantially pure sine wave configuration. The problem is further to devise a system, involving the above principle, which will produce a continuous succession of such waves, by which is meant a condition in which, for instance, there are no intervals durng which there is zero current.

The first mentioned result is attained in the present invention by utilizing that characteristic of a three-electrode electric discharge device by virtue of which current can flow from the anode to the cathode only when the anode has impressed thereon a positive potential and when, at the same time, the third electrode has impressed thereon a potential greater than a definite critical value, this potential depending on the characteristic of the particular tube. The interval during which the necessary conjunction of conditions occurs may easily be made to be less than the period of the alternating voltages which are impressed on the anode and third electrode, which period is necessarily that characteristic of the polyphase system from which they are derived. This

is accomplished in the present invention by deriving the potentials to be impressed on the anode and third electrode from parts of the polyphase system between which there is a phase difference at a given instant. For example, if the anode and third electrode are given their potentials by connecting both to the same point in the system, the maximum and minimum of the impressed voltage curves would be coincident and the operation of the tube would not be substantially different from that of a two electrode tube, the interval of current flow obviously being the same as that of the impressed potential, if the constants of the tube are adjusted so that current is caused to flow only when the anode and third electrode are both positive. On the other hand, if the connections are made to opposite ends of a transformer or generator winding the potentials will have exactly opposite phases and there will be no interval during which current will flow. In a polyphase system, however, it is possible to derive potentials differing from each other by any phase difference desired and if two potentials thus derived and differing in phase by an angle somewhere between zero and 180 electrical degrees are impressed on the anode and third electrode, the current will flow during an interval less than the period of one alternation of either of the impressed potentials. There is thus obtained one of the three essential conditions named above. It is apparent that since the interval of current flow depends on a relation between two sine waves, the current wave will increase from a zero value to a maximum and decrease to a zero value without discontinuity. By refinement of details the curve can be made to approximate closely a pure sine wave.

By the means described above, a single alternation corresponding to any frequency whatever can be obtained. However, in order to perpetuate a uniformly recurring succession of such alternations this period must have a definite value determined by the period of the impressed voltage wave and by the symmetry of the figure expressing the vectorial relations of the various quantities. For example, the period must be an integral divisor of the period of the impressed voltage, that is, the multiplication factor must be an integral number and, further, the multiplication factor must have a definite relation to the number of phases of the polyphase system.

It will be hereinafter shown that the multiplication factor equals the number of phases. A simple embodiment of the invention involving a two-phase source will be shown and it will be shown that a frequency doubling will be possible with the use of two tubes associated with one of the two-phase windings in a manner similar, so far as the filament and plate are concerned, to the analogous use of two rectifiers with a three terminal transformer secondary for rectifying both halves of the cycle of the single phase current impressed on the primary, the grids being connected to the other phase. The resulting current however will be an impulse current having a double frequency, the negative portions of the curve being suppressed. The negative alternations of the current can be secured by employing another pair of tubes similarly related to each other as in the case of the first two tubes and connected to the two-phase system in a similar manner, the connections being tapped in, however, at points displaced 90 electrical degrees from the corresponding points of the previously mentioned tubes. This results in the superposition on the system previously described of another double frequency impulse system and if all four filaments are connected together and connected to the neutral point of the source a quadruple frequency impulse current will result. By connecting the work circuit inductively to the system and spacing the impulse currents derived from the two pairs of electric discharge devices, so that a positive impulse is followed by a negative impulse successively and continuously without overlapping, a true double frequency alternating current may be obtained.

It has been stated that an alternating current of a multiple frequency the multiple of which is equal to the number of phases of the supply source, or that an impulse current of double this multiple, can be secured. Although the system involving the use of a two-phase system has been assumed in the above description, the principle of the invention may be applied to any system in a manner analogous to that to be illustrated with reference to a two-phase system, and the relation between the number of tubes, multiplication factor, and number of phases will apply equally thereto. It is well known that from a two or three phase system, a system having any number of phases can be evolved.

In the description preceding, the term "electric discharge device" has been frequently employed. By this expression is meant any species of that generic class of devices characterized by an electron emitting cathode and an anode, without regard to the particular means employed to excite the cathode to electron emission or to the degree to which current flow is dependent on gas ionization, as distinguished from a pure electron discharge. Both the mercury vapor rectifier devices and the so called audion tube are included in this generic class and may be used in the system described, although, for practical reasons, it

is preferred to use an audion tube and such means will be assumed in the description of the practical embodiments which follow.

For a more detailed disclosure of the invention, reference is made to the description which follows, taken in connection with the annexed drawings in which the invention is embodied in specific forms and in which Fig. 1 shows the principle of the invention as applied to a two-phase system and designed for doubling the frequency; Fig. 2 illustrates the relations of the various electrical quantities of the system of Fig. 1; Fig. 3 shows the characteristic performance curve of a vacuum tube that may be used in the system of Fig. 1; and Fig. 4 shows an extension of the system of Fig. 1 including means for rendering both halves of the high frequency alternating current available.

At the left of Fig. 1 is shown a star-connected two-phase system, the coils indicating the source of two-phase currents and which may be either the secondaries of star-connected transformers or the windings of a two-phase generator. The curves "a'" "b'" "a'_1" "b'_1" of Fig. 2 represent the voltages between the junction point of the windings and the ends, the lettering being made to correspond with that of Fig. 1. The showing of the voltage "b" in quadrature relation with voltage "a'" is in accordance with well known theory and it is equally apparent that the voltage of windings "a_1" is displaced 180 electrical degrees from the voltage of winding "a." Although the voltage "a'" is shown as leading the voltage "b'," it is well understood that the direction of rotation of the resultant field is dependent on the connection of the leads in the case of the transformer and may be reversed by interchanging the connection of the leads corresponding to one phase. In the case of a generator the direction of rotation is determined by the direction of rotation of the rotor.

Confining our attention for the moment to windings "a" and "b" and vacuum tube T_1, it is proposed to demonstrate that, by the means of the arrangement here shown, that portion of curve I in Fig. 2 which is indicated by reference character T'_1 may be obtained. It is noted that the filament of tube T_1 is connected through load C with the neutral point of the windings while the plate is connected to the end of winding "a." The grid is connected to winding "b" and has an alternating potential impressed thereon from the winding, a constant negative potential being impressed on this grid by means of the polarizing battery shown. This negative grid potential is adjusted to equal the potential corresponding to "od" of the curve illustrated in Fig. 3. The curve here illustrated is the conventional space current-grid potential characteristic, I_B and E_C being used to indicate respectively the axes of ordinates and abscissæ. The subscripts B and C are here used in deference to the nomenclature of the tube art, especially as applied to amplifiers, in which the space current source is designated the B battery and source of grid voltage C battery. If the grid is given a negative potential equal to potential "od" current can flow in the space circuit only in the interval during which a potential is impressed on the grid by the positive alternation of the wave from winding "b." Further, as is well known, a current can flow only when the plate is positive with respect to the filament. Accordingly, as a result of the conditions laid down above, current will flow in the space circuit of the tube and through load C only during the interval in which positive potentials are impressed upon both the grid and plate from the polyphase source.

Noting now Fig. 2, the interval during which both grid and plate are positive corresponds to the time period of the resultant current wave I and the alternation of the current wave designated T'_1, at the left of the figure, represents the flow of current during that particular time interval. The curve T'_1 may be caused to have substantially a sine wave form by using the proper ratio of grid and plate potentials as by tapping one or both at a proper point intermediate the neutral and the end of the winding. The maximum amplitude of the current wave depends on the amplifying characteristic of the particular tube used.

In a manner identically the same as the above, the alternation T'_2 is obtained from tube T_2 using windings "a_1" and "b_1". It is seen that windings "b_1", "a_1" and b, a are similarly related in the two pairs and that the method of obtaining these two alternations is entirely similar, except as to the use of the grids, to the use of two rectifier tubes to rectify both halves of a single phase alternating current.

By the system described above, a double frequency impulse current, illustrated by the positive alternations of current I in Fig. 2, is obtained. A current of this form is capable of many of the uses usually identified with an alternating current of the conventional kind. However, it is convenient for many purposes that the current have the conventional alternating wave form and in Fig. 4 there has been illustrated a system by means of which both the positive and negative alternations can be secured.

In the system illustrated by this figure, the tubes T_1 and T_2 function identically as the tubes in Fig. 1 and by their relation to the polyphase source cause a double frequency impulse current, corresponding to T'_1 and T'_2 of Fig. 2, to flow in circuit A

and hence, by means of transformer T a similar current will be produced in circuit C, which includes the load and which may be tuned to the high frequency, if desired, by a condenser as shown. The tubes T_3 and T_4 are so arranged that current will flow therethrough during intervals between the positive alternations T'_1 and T'_2 of the current shown in Fig. 2. In fact if the curve of current I in this figure were made to represent the current flowing in these tubes and in a common load circuit the curve would indicate an impulse current of quadruple frequency and such a wave form could be obtained by connecting the filaments of tubes T_3 and T_4 to the same point as the filaments of tubes T_1 and T_2, instead of as shown. It is noted, however, that in the system here shown the current in tubes T_3 and T_4 are caused to flow through a separate circuit B which is arranged oppositely to circuit A with relation to the neutral point of the source. These windings A and B constitute halves of the primary of a transformer T and accordingly the current in the secondary of this transformer, which circuit includes the load, has the character shown by the complete curve I. It is apparent that the curve represents a time alternating current having a double frequency.

Although Fig. 4 shows the invention embodied in a form by means of which a polyphase current can be converted into a single phase current having the same wave form but a higher frequency, it is to be understood that the extension of the system of Fig. 1 to cover a system capable of functioning to produce a current indicated by the complete curve I can be accomplished by other means than that shown of Fig. 4. For example, the tubes T_3 and T_4 can be related to a two-phase system similar to that shown in Fig. 1, but in which the polarities of the ends of the windings are reversed, the current from the four tubes being caused to flow through the common load circuit. A two-phase system of this type can be derived from that shown in Fig. 1 by transformation, making use of the 180 degree phase angle of a transformer.

Further, it should be pointed out that the phrase "polyphase source" may include the secondary of a system of transformation or a potentiometer, etc., and is not necessarily limited to a primary source of electromotive forces as, for example, the windings of a generator.

It should also be emphasized again that the principles of the invention as illustrated in Figs. 1 and 4 can be used, equally well, with a polyphase source having any number of phases and hence, that any desired multiplication of frequency can be secured, it being known that such a polyphased energy system can be derived from a two-phase or three-phase source.

What is claimed is:

1. The method of frequency conversion which comprises utilizing an alternating E. M. F. to establish unidirectional discharge current, and variably impeding said discharge current in accordance with a second alternating E. M. F. of the same frequency as the first but of different phase.

2. The method of frequency multiplication which comprises rectifying an alternating E. M. F. to establish uni-directional current, and variably impeding said current in accordance with an E. M. F. of the same frequency but of a different phase.

3. The method of deriving higher frequency from given polyphase current, which comprises establishing uni-directional current by rectifying the current of each of said phases, variably impeding each of said uni-directional currents in accordance with currents similarly derived from respectively adjacent phases, and combining the variable currents thus produced, whereby an alternating current of higher frequency than that of said given polyphase current is derived.

4. The method of obtaining a multiple frequency current from given polyphase alternating currents which comprises utilizing the voltages from adjacent phases to establish uni-directional currents corresponding to different phases and causing the uni-directional current of one phase to variably impede the uni-directional current of another phase.

5. The method of deriving a variation current of relatively greater frequency from polyphase currents of a different frequency, involving the use of a three-electrode electric discharge device, which method consists in impressing a voltage of one phase on the impedance controlling circuit of said device and impressing a voltage from another phase upon the space current circuit of said device, whereby the duration of each of the resulting current impulses in the space current circuit is less than a half period of either of the impressed voltages.

6. A system for frequency conversion comprising, in combination, a source of alternating electromotive force, means cooperating therewith for establishing a unidirectional discharge current, means for obtaining an alternating electromotive force having the same frequency as that from said source but differing therefrom in phase, and means for variably impeding said discharge current in accordance with said last mentioned electromotive force.

7. In a system for frequency conversion, in combination, a polyphase source of alternating currents, a three-element electric discharge device, comprising a cathode, an

anode, and an impedance controlling element, means connecting said cathode to a point in said source, and means respectively connecting said anode and impedance controlling element to points in said source differing from each other.

8. A system for frequency conversion including in combination a polyphase source of alternating voltages having a common or neutral connection, and a three-electrode electric discharge device which includes a cathode, an anode and an impedance controlling element, said cathode being connected to said neutral point of the source, and the anode and third electrode being connected respectively to points in the system, the potentials of which with respect to the neutral point, differ from each other in phase by approximately 90 degrees.

9. A system for obtaining a double frequency impulse current from a two-phase alternating current source which includes, in combination, a two-phase star connected system, two electric discharge devices each having a cathode, an anode and an impedance controlling element a load circuit connecting the cathodes of said device to the neutral point of the connected system, means connecting the anode and impedance controlling element of one device respectively to two adjacent legs of the star connected system, and means connecting the anode and impedance controlling element of the other device respectively to the remaining two legs, the connection of the two devices being symmetrically arranged with respect to the two-phase source.

10. A system for frequency conversion comprising, in combination, a star connected two-phase source, two three-element electric discharge devices each including a cathode, an anode and a control element, a load circuit connected between the cathodes of said devices and the neutral point of the star connected source, means connecting the anodes of the respective devices symmetrically to one of the two-phase windings at points on either side of the nuetral point of said source, means connecting the respective control elements symmetrically to the other one of the two-phase windings, a polarizing battery included in each control element circuit and adjusted so that current can flow in the space current circuit of the device only during the intervals when a positive potential is impressed from the source on the respective control elements and means for adjusting the connections of the anodes and control elements so as to give a current of substantially sine wave form.

11. A system for obtaining from a two-phase alternating current system a single phase alternating current having a double frequency which includes in combination, a two-phase star connected alternating current source, a load supply transformer having a primary winding with a mid tap connection to a neutral point of said source, two three-element electric discharge devices having cathodes connected to one terminal of said primary winding, anodes connected to points on one of the two-phase windings symmetrically spaced from said neutral point, and control elements similarly connected to points in the other winding, a second pair of three-element electric discharge devices having their cathodes connected to the other terminal of said primary winding, and anodes and control elements connected to the two-phase source in a manner identical with that of the other electric discharge devices, but to points displaced from the corresponding points thereof by one leg of the star connected two-phase source.

In witness whereof, I hereunto subscribe my name this 15 day of Dec., A. D., 1920.

MILTON K. AKERS.