Jan. 15, 1924. 1,480,708

C. LE G. FORTESCUE

BALANCED PHASE CONVERTING SYSTEM

Original Filed Dec. 13, 1917 4 Sheets-Sheet 1

Fig. 1.

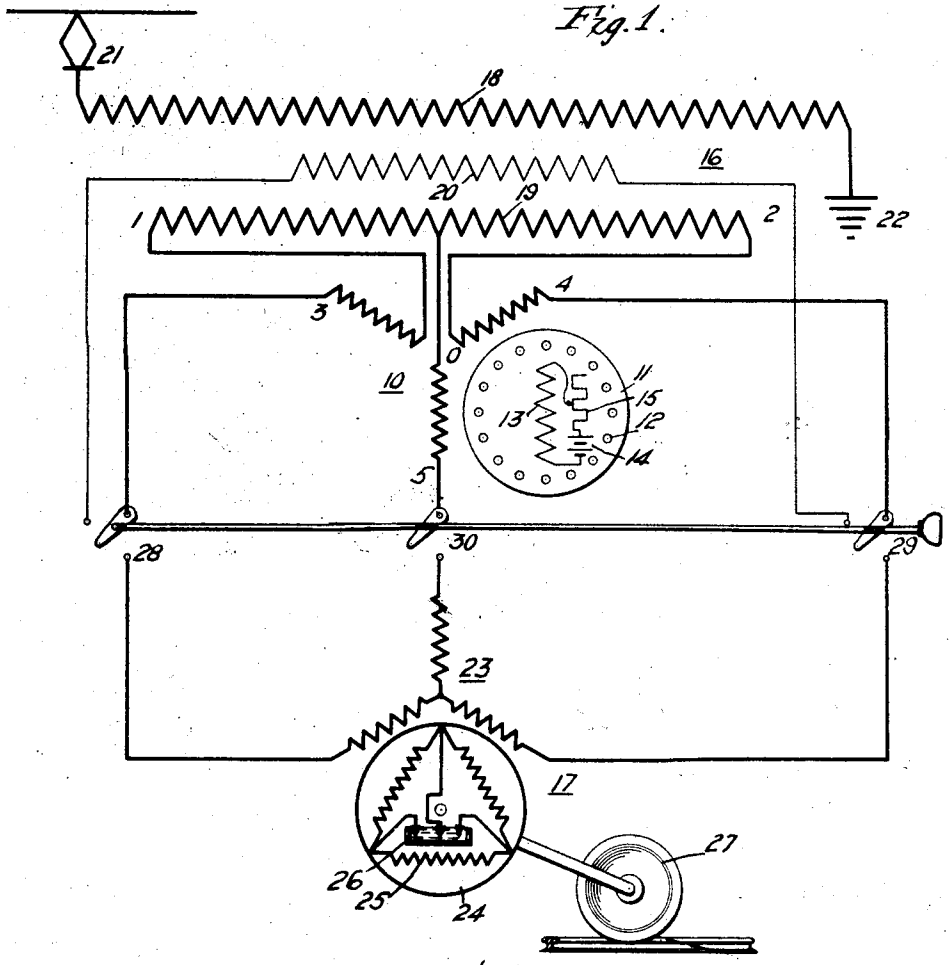
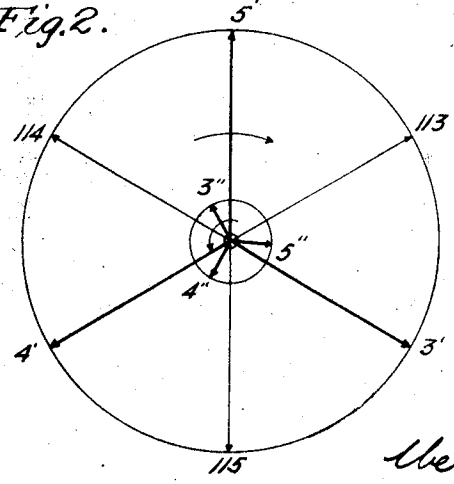


Fig. 2.



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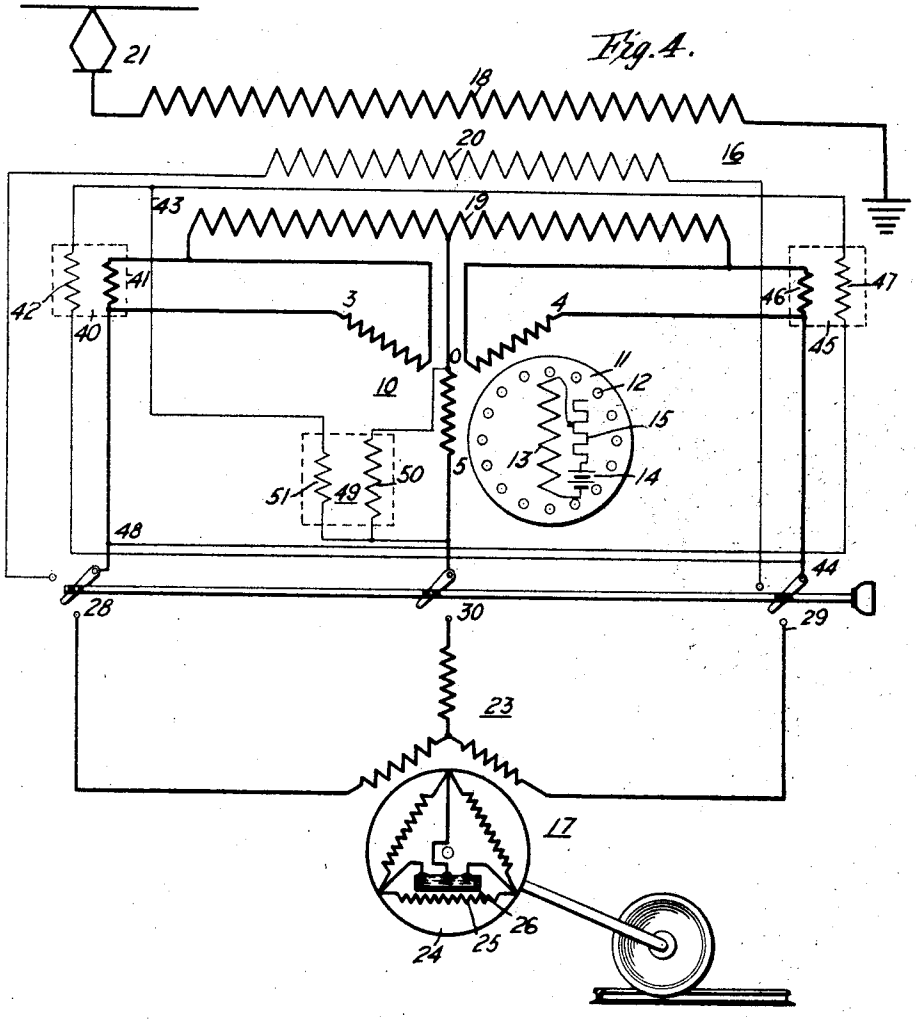
Jan. 15, 1924. 1,480,708

C. LE G. FORTESCUE

BALANCED PHASE CONVERTING SYSTEM

Original Filed Dec. 13, 1917 4 Sheets-Sheet 2

Fig. 4.



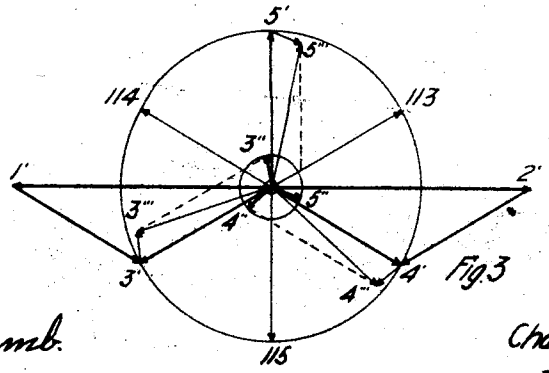


Fig. 3

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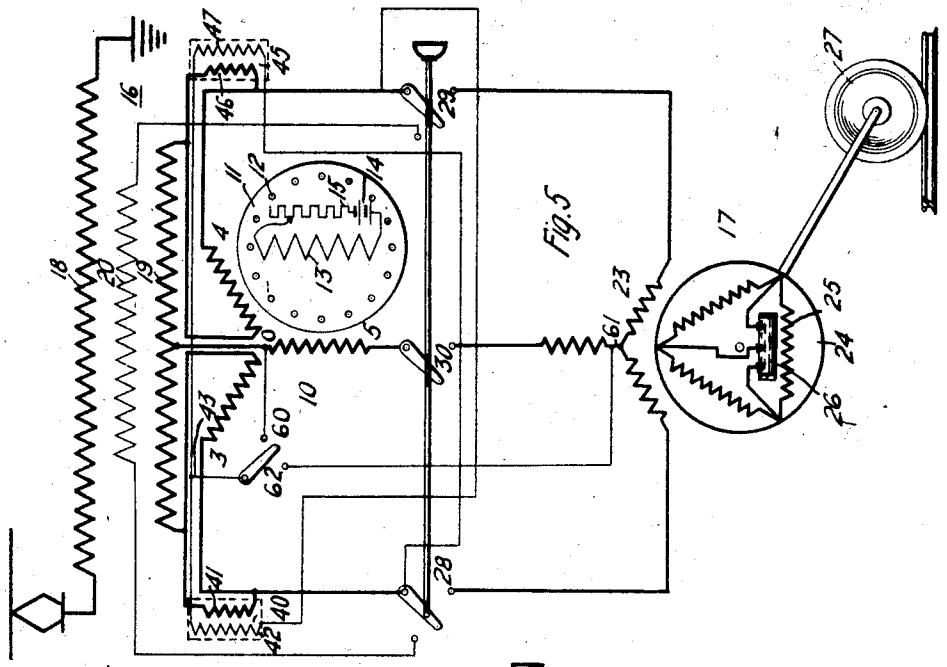
ATTORNEY

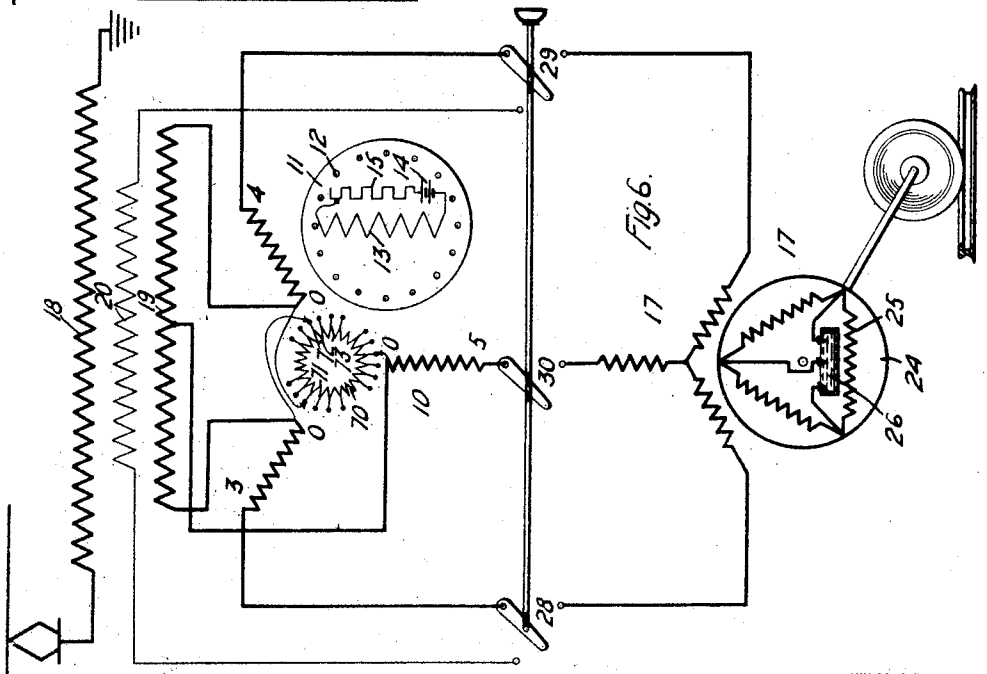
Jan. 15, 1924. 1,480,708

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BALANCED PHASE CONVERTING SYSTEM

Original Filed Dec. 13. 1917 4 Sheets-Sheet 3





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Jan. 15, 1924. 1,480,708

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BALANCED PHASE CONVERTING SYSTEM

Original Filed Dec. 13, 1917 4 Sheets-Sheet 4

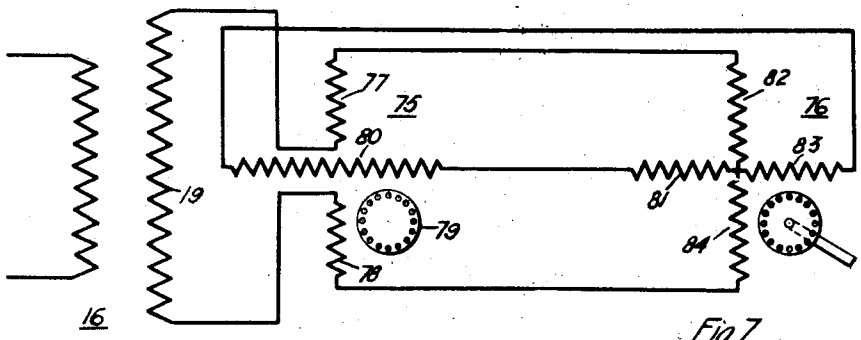


Fig. 7.

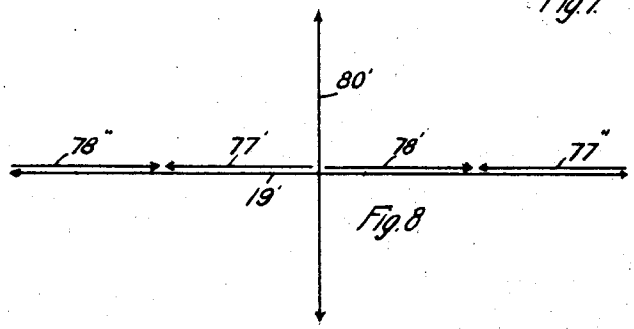


Fig. 8.

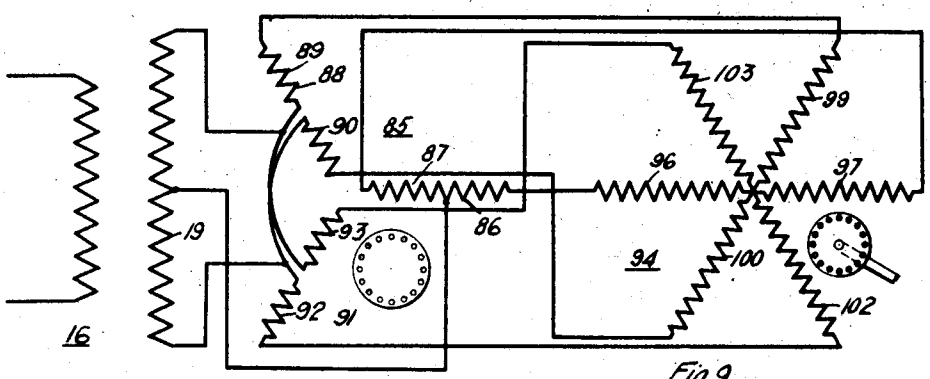


Fig. 9.

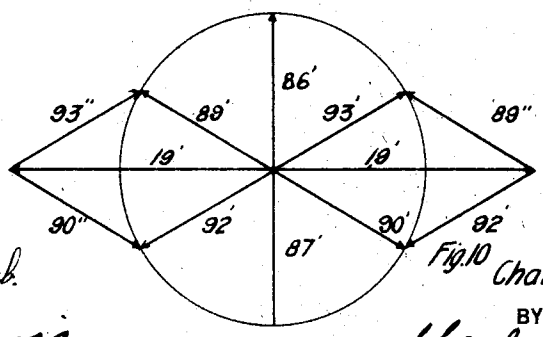


Fig. 10.

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UNITED STATES PATENT OFFICE.

CHARLES LE G. FORTESCUE, OF PITTSBURGH, PENNSYLVANIA, ASSIGNOR TO WESTINGHOUSE ELECTRIC & MANUFACTURING COMPANY, A CORPORATION OF PENNSYLVANIA.

BALANCED PHASE-CONVERTING SYSTEM.

Application filed December 13, 1917, Serial No. 206,932. Renewed December 30, 1921. Serial No. 526,035.

To all whom it may concern:

Be it known that I, CHARLES LE G. FORTESCUE, a subject of the King of Great Britain, and a resident of Pittsburgh, in the county of Allegheny and State of Pennsylvania, have invented a new and useful Improvement in Balanced Phase-Converting Systems, of which the following is a specification.

My invention relates to systems of phase conversion, as, for example, between single-phase and polyphase circuits or vice versa, and it has for its object to provide a system of the character designated wherein the polyphase circuits are automatically maintained in substantial balance, irrespective of voltage drops in the converter and associated apparatus.

Other objects of my invention are to provide means whereby a converter of the type above indicated may be maintained in operation under no-load conditions and to provide means for the interchange of magnetizing energy between the phase-converter and the polyphase system.

In the accompanying drawing, Fig. 1 is a diagrammatic view of a phase-converter, together with its associated apparatus embodying a preferred form of my invention; Figs. 2 and 3 are vector diagrams illustrating the operation of the system shown in Fig. 1; Figs. 4, 5, 6, 7 and 9 are views similar to Fig. 1 and illustrating modified forms of my invention; and Figs. 8 and 10 are vector diagrams explanatory of the systems of Figs. 7 and 9, respectively.

It is a well known fact that if a polyphase system be energized from a single-phase system through a phase-converter of the dynamo-electric type, the effect of the reactive and ohmic drops within the converter is to produce unbalancing of the polyphase electromotive forces. Similarly, when a single-phase circuit is energized from a polyphase circuit through a phase-converter of the dynamo-electric type, the energy for said single-phase circuit is not derived equally from the different phases of the polyphase supply because of the reactive and ohmic drops within the converter and, consequently, the polyphase supply circuit is unbalanced.

An unbalanced set of polyphase vectors may be considered as produced by the superposition of a fixed vector of oscillating magnitude upon a set of balanced polyphase vectors and said fixed vector may be readily resolved into two oppositely rotating vectors of equal length and of half the maximum magnitude of said fixed vector, the effect of each of said rotating vectors being produced by a polyphase system.

Thus, an unbalanced polyphase system may be resolved into a balanced major portion having a given phase sequence and into a minor portion comprising two oppositely rotating polyphase components or components having opposite phase-sequence. That component of the single-phase unbalancing electromotive force which is rotating in the same direction as said major polyphase component coalesces therewith, leaving the polyphase unbalanced system resolved into a major balanced polyphase component having one phase-sequence and a minor polyphase component having the opposite phase-sequence, said latter component being produced in phase-converting systems by the ohmic and reactive drop electromotive forces.

For a more rigid proof of this subject-matter, attention is directed to the appendix of an article by R. E. Gilman and the applicant appearing in the Proceedings of the American Institute of Electrical Engineers for October, 1916, and entitled "Single phase power service from central stations."

In the past, attempts have been made to balance the output of phase-converters by eliminating said reversely rotating minor component, as by an auxiliary booster machine. In accordance with the present invention, I attack this problem from a radically different viewpoint and, in effect, reverse the phase sequence of said major polyphase component, thus causing it to rotate in the same direction as the minor polyphase component produced by the ohmic and reactive drops. This effect is produced by combining with the major polyphase component auxiliary electromotive forces of such magnitude and phase as to produce a resultant system of polyphase electromotive forces of substantially the same magnitude as said component electromotive forces but having the opposite phase sequence in the distributing system. Said resultant polyphase system and the minor polyphase component being of like frequency, phase-number and phase sequence, coalesce to produce

balanced polyphase resultant electromotive forces having slight phase displacement from the major component, as reversed, but otherwise being substantially unaffected by the minor component.

I am thus enabled to supply substantially balanced polyphase electromotive forces from a single-phase source or to substantially equally distribute a single-phase load over the different phases of a polyphase system, irrespective of the magnitude of the load and, as my system embodies no relays or auxiliary machines, it is simpler and more effective in its operation than systems proposed in the past and embodying shifting transformer taps and auxiliary booster machines for their operation.

Referring to the accompanying drawing for a more detailed understanding of my invention, I show a phase-converter at 10 in Fig. 1, said converter embodying stator windings 0—3, 0—4 and 0—5 and a rotor 11 provided with a short-circuited winding 12 and with a direct-current exciting winding 13 for synchronous operation. In order to adjust the power-factor, the direct-current excitation of the winding 13, derived from a source 14, may be adjusted by a rheostat 15.

The converter 10 is shown as applied to locomotive service and is thus associated with a transformer 16 and with a propulsion motor 17. The transformer 16 embodies a primary winding 18, a main secondary winding 19 and an auxiliary secondary winding 20. Energy for the operation of the locomotive is derived from a trolley 21, the primary winding 18 being connected between said trolley and ground, indicated at 22.

The propulsion motor 17 is shown as embodying a star-connected stator member 23 and a rotor member 24 provided with a delta-connected winding 25. The speed regulation of the motor 17 may be effected by interconnecting the terminals of the delta winding 25 to an adjustable rheostat 26, said rheostat being reached through suitable slip rings (not shown). The motor 17 is coupled to a vehicle wheel 27, supplying energy thereto during motoring and receiving energy therefrom during recuperative operation.

The three-phase windings 0—3, 0—4 and 0—5 of the converter 10 are mutually distinct and the phase-winding 0—3 may be connected between the left-hand terminal 1 of the main secondary winding 19 and a terminal of the motor stator winding 23 by a switch 28. In like manner, the converter phase winding 0—4 may be connected between the right-hand terminal of the main secondary winding 19 and a terminal of the motor stator winding 23 through a switch 29. The phase winding 0—5 of the converter 10 may be connected between substantially the mid point of the converter winding 19 and the remaining terminal of the motor stator winding 23 through a switch 30. The switches 28 and 29, when moved to their left-hand positions, disconnect the phase windings 0—3 and 0—4 from the motor stator winding and interconnect said windings through the auxiliary secondary winding 20 for a purpose to be hereinafter more fully pointed out. While, for clearness and simplicity of illustration, I have shown the switches 28, 29 and 30 of the simple knife-blade type interconnected for simultaneous operation, as by a rod 31, it will be understood by those skilled in the art that, in actual construction, power-operated switches would probably be employed in place thereof, said power operated switches being controlled by a suitable master controller and either mechanically or electrically interlocked so that connection to the motor stator winding must be broken before connection to the auxiliary secondary winding 20 is completed and vice versa.

Having thus described the arrangement of a system embodying my invention, the operation thereof, during motoring, may be explained as follows.

Upon starting the converter 10 into operation by any suitable means, such, for example, as a starting motor, the converter continues to run as a single-phase motor, deriving single-phase energy from the transformer 16 and supplying polyphase energy to the motor 17. The phase-relation of the electromotive forces produced in the respective phase windings of the converter 10 may be indicated by the vectors 0′—3′, 0′—5′ and 0′—4′ in Fig. 2, said electromotive forces being substantially balanced and having clockwise phase sequence, constituting the major component of the converter output. The drops within the converter phase windings may be indicated by the polyphase vectors 0′—3″, 0′—4″ and 0′—5″, having the opposite phase sequence from the main vectors because of the fact that, in the motoring phase or phases of the converter, the current is flowing against the generated electromotive force, whereas, in the generator phase or phases, the current is flowing with the generated electromotive force. The back electromotive forces of the respective motor windings are indicated by vectors 0—113, 0—114 and 0—115.

The effect of connecting the inner ends of the phase windings 0—3 and 0—4 to the outer ends of the winding 19, rather than connecting said inner ends to a neutral point in the converter, is to supply to the motor a system of polyphase resultant electromotive forces similar to the major component of the converter electromotive forces of Fig. 2 but having the opposite phase sequence

with respect to the distributing system. In effect, this result is secured by interchanging the location of the vectors 0′—3′ and 0′—4′, as will be noted by reference to Fig. 3. In this figure, the vector 0′—5′, denoting the generated electromotive force of the phase winding 0—5, is shown located as in Fig. 2. The inner terminal of the phase winding 0—5 is connected to substantially the mid point of the winding 19 and thus the electromotive force of the winding 19 may be plotted as a vector 1′—2′. The phase converter is designed for operation at such voltage that the vector 1′—2′ is greater than the vector 0′—5′ in the ratio of $2\sqrt{3}$ to 1. The fact that the inner end of the phase winding 0—3 is connected to the left-hand terminal of the winding 19 demands the construction of the vector 1′—3′, representing the generated electromotive force of said winding, from the left-hand end of the vector 1′—2′, thus locating the point 3′ in Fig. 3, denoting the phase of the electromotive force of the point 3 in Fig. 1, at the location of the point 4′ in the diagram of Fig. 2. In like manner, the vector 2′—4′ in Fig. 3, denoting the electromotive force of the phase winding 0—4 in Fig. 1, must be constructed from the right-hand terminus of the vector 1′—2′, thus locating the point 4′ in Fig. 3 at the locus of the point 3′ in Fig. 2.

Thus it will be noted that, by virtue of the inclusion of the transformer winding 19 in the circuit in the manner indicated, the phase-locations of the vectors 0′—3′ and 0′—4′, denoting the phases of the electromotive forces at the terminals 3 and 4 of the converter 10 have in effect been interchanged, thus reversing the phase sequence of the major component of the output electromotive forces of the phase converter as applied to the load. The phase sequence of the drops 0′—3″, 0′—4″ and 0′—5″ has been unchanged by the connection and thus, in the system of Fig. 3, the major and minor components of the output electromotive forces of the phase-converter have the same phase sequence and may be combined into the resultant balanced electromotive forces 0′—3‴, 0′—5‴ and 0′—4‴, substantially equal and opposite to the respective motor back electromotive forces 0—113, 0—115 and 0—114.

The balanced polyphase electromotive forces thus produced may be applied to the propulsion motor to produce rotation thereof in the desired direction by suitable switching means and serve to operate the motor at maximum efficiency, as is well understood.

During recuperation, the operation of my system is substantially the same as above described. The effect of the ohmic and reactive drops in the converter 10 would tend to derive unbalanced polyphase electromotive forces from the machine 17 but said electromotive forces are reversed in phase sequence and forced to assume the same sequence as the drops by the system of connections shown and thus the resultant polyphase voltages supplied to the converter 10 by the machine 17 are substantially balanced and an effective recuperative effect may be produced.

If it be desired to disconnect the motor 17, the switches 28, 29 and 30 may be simultaneously opened and, immediately thereafter, the winding 20 may be connected between the terminals 3 and 4 of the phase-converter, through the operation of the rod 31, thus providing a closed circuit through the windings 19 and 20 and the phase windings 0—3 and 0—4. This circuit serves to maintain the converter in operation, the electromotive force of the winding 20 opposing the winding 19 and thus holding the operating current down to a reasonable value, performing the function of a current-limiting resistor without involving an appreciable ohmic loss.

While the system described to this point is effective in producing balanced output electromotive forces, the degree of over or under excitation of the phase-converter rotor will exert a slight unbalancing effect and this undesired effect may be largely eliminated by permitting the circulation of wattless currents between the motor 17 and the converter 10 without causing said wattless currents to traverse the winding 19. In view of the phase reversal occasioned by the winding 19, however, the wattless currents for a phase of the motor 17 should be derived, not from the phase of the converter to which said motor phase winding is directly connected but from one of the other windings.

Referring to Fig. 4, the principal parts of the converter system are as previously shown. An auxiliary transformer 40 comprises a primary winding 41 connected across the terminals of the winding 0—3 and a secondary winding 42 connected between a neutral point 43 and the right-hand supply main at 44. In like manner, an auxiliary transformer 45 comprises a primary winding 46 in parallel relation to the winding 0—4 and a secondary winding 47 connected between the neutral point 43 and the left-hand supply main at 48. Likewise, an auxiliary transformer 49 may be employed comprising a primary winding 50 connected in parallel relation to the phase-winding 0—5 and a secondary winding 51 connected between the neutral point 43 and the central supply main. By thus inductively coupling the phase-converter and the propulsion motor in proper phase sequence, a path for wattless circulating currents between the two machines is afforded, the effect of said circulating currents being to

correct the power-factor in a degree determined by the over-excitation of the phase-converter.

The system of Fig. 5 is, in general, similar to that of Fig. 4 but the transformer 49, together with the connection to the central main is eliminated. The neutral point 43 may be connected to the system either at the point 0, adjacent the winding 19 or at the neutral point 61 of the motor stator winding 23 by the manipulation of a switch 62, as is dictated by the specific operating conditions. The first connection is employed for power factor correction when the motor is disconnected and the latter is preferable when the motor is in operation, especially under heavy load.

In the system of Fig. 6, a wattless-current operating effect similar to that just described may be produced by suitable modification and manipulation of the converter windings without the use of auxiliary transformers. The converter 10 is provided with phase windings 0—3, 0—4 and 0—5, as before, and, inside the points of attachment of the leads to the winding 19, an auxiliary delta-connected converter winding 70 may be provided. Said auxiliary winding is provided with adjustable tap points at 71, 72 and 73, and a lead from the winding 0—3 may be connected to any of the taps at 72, substantially in phase with the winding 0—4. In like manner, a lead from the winding 0—4 may be connected to any one of the taps 71, substantially in phase with the winding 0—3. A lead from the winding 0—5 may be connected to any one of the taps at 73. By suitable manipulation of the taps 71, 72 and 73, the phase and magnitude of the circulating currents interchanged between the two machines may be modified and thus suitable power-factor correction may be obtained without voltage unbalance. By the crossing of the leads from the windings 0—3 and 0—4 to the winding 70, the desired compensation for the phase reversal occasioned by the specific connection of the winding 19 is obtained.

The systems described to this point have embodied three-phase operation but the principles of my invention are equally applicable to systems embodying any desired phase number, either star or delta connected. Thus, in Fig. 7 I illustrate a four-phase system embodying a quarter-phase converter 75 connected to a quarter-phase motor 76. The converter 75 embodies primary windings 77 and 78, a secondary winding 79 and a tertiary winding 80. The motor 76 embodies primary windings 81 to 84, inclusive. Energy is supplied to the system through a transformer 16, the secondary winding 19 of said transformer being inserted between the inner terminals of the converter windings 77 and 78.

Vectorially, the operation of the system thus described is similar to that of the systems of the earlier figures. Referring to Fig. 8, the generated electromotive forces of the converter windings 77, 78 and 80 may be indicated by vectors 77′, 78′ and 80′, respectively, assuming the converter 75 to be interconnected. The fact, however, that the windings 77 and 78 are connected together only through the supply winding 19 produces a reversal of the phases of the vectors 77′ and 78′, as follows. The electromotive force of the winding 19 may be plotted as the vector 19′ and thus the vector 78′ is moved bodily to the position 78″ and the vector 77′ is moved bodily to the position 77″. As a result, the electromotive force applied to the motor winding 82 is substantially that indicated by the vector 78′, and the electromotive force supplied to the motor winding 84 is substantially that indicated by the vector 77′. The vector 80′ being unaffected, the phase sequence of the generated electromotive forces of the converter 75 is reversed by the winding 19 due to the virtual interchange of the vectors 77′ and 78′, and thus the desired coincidence in phase sequence between the generated and drop electro-motive forces of the converter is secured.

Referring to Figs. 9 and 10, a six-phase system is illustrated. A converter 85 embodies a tertiary winding having two portions 86 and 87. Said converter further embodies a primary winding having a phase portion 88 spaced substantially 120° from the tertiary winding and embodying distinct portions 89 and 90 and an additional primary winding 91, likewise spaced 120° from the tertiary winding and embodying distinct portions 92 and 93. The outer terminals of the different converter windings 86, 87, 89, 90, 92 and 93 are connected respectively to the terminals of the phase windings 96, 97, 99, 100, 102, 103, respectively, of a six-phase load device such, for example, as a motor 94. The remaining free terminals of the converter windings 90 and 92 are interconnected and jointly attached to the lower terminal of the transformer supply winding 19 and, similarly, the free terminals of the windings 93 and 89 are interconnected and jointly attached to the upper terminal of the winding 19. The mid point of the converter tertiary winding is connected to substantially the mid point of the winding 19.

The resultant vector relations are shown in Fig. 10 and are substantially a duplication of those shown in Fig. 3. The generated tertiary electromotive forces may be indicated by vectors 86′ and 87′, respectively, in quadrature to a vector 19′, indicating the electromotive force of the supply winding 19. Neglecting the displacing effect of said winding 19, the electromotive forces of the

supply windings 89, 90, 92 and 93 may be indicated, respectively, by vectors 89′, 90′, 92′ and 93′. These last named vectors, however, must be plotted from the ends of the vector 19′, because of the specific connection employed, and thus said vectors are in reality located as indicated at 89″, 90″, 92″ and 93″, respectively. Thus, in effect, the positions of the vectors 89′ and 93′ and of the vectors 92′ and 90′ are interchanged and the direction of phase rotation of the output electromotive forces of the converter is reversed without correspondingly affecting the drop electromotive forces, as is desired for balancing purposes.

It will be noted that the transformer secondary winding 19, having terminal connections and a mid-tap connection, is merely one specific case representing an extreme condition of an unbalanced three-phase system, since said winding provides three circuits or phases having dissymmetrical electromotive forces, which, when vectorially added, are capable of forming a closed polygon of forces. It will be noted, also, that an unbalanced polyphase system of electromotive forces may be resolved into two balanced systems, one having the forward sequence of phases and the other the backward phase-sequence.

When the apparatus is viewed in this light it becomes evident that the series machine 10 is rotating in synchronism with one of said balanced component systems which we may call the backward phase-sequence system, thereby developing what may be termed a synchronous impedance against the backwardly rotating component electromotive forces. The forwardly rotating system of balanced electromotive forces produces, in the backwardly rotating rotor of the series machine, double-frequency electromotive forces, and the resultant double-frequency currents circulating in the low-impedance damper windings 12 serve to neutralize the impedance of the primary windng to currents of the forward phase-sequence. In this manner, the phase-balancing function of the series machine is accomplished.

While I have shown my invention in a plurality of forms, it will be obvious to those skilled in the art that it is not so limited but is susceptible of various minor changes and modifications without departing from the spirit thereof and I desire, therefore, that only such limitations shall be placed thereupon as are imposed by the prior art or indicated in the appended claims.

I claim as my invention:

1. The combination with a source of alternating electromotive forces providing two sets of polyphase electromotive forces of like phase-number but of opposite phase-sequence, of means for, in effect, reversing the phase sequence of one of said sets with respect to the other, means providing an electric circuit, and means for supplying said reversed polyphase electromotive forces, together with the unchanged polyphase electromotive forces, to said circuit.

2. The combination with a source of alternating electromotive forces providing two sets of substantially balanced polyphase electromotive forces of like phase-number but of opposite phase-sequence, of means for, in effect, reversing the phase-sequence of one of said sets with respect to the other, means providing an electric circuit, and means for supplying said reversed polyphase electromotive forces, together with the unchanged polyphase electromotive forces, to said circuit, whereby a substantially balanced resultant electromotive force is supplied thereto.

3. The combination with a polyphase dynamo-electric machine wherein the electromotive force drops in the different phase windings have the opposite phase sequence from the electromotive forces of said windings, of means for, in effect, reversing the phase sequence of one of said sets of electromotive forces relative to the other.

4. The combination with a polyphase dynamo-electric machine wherein the electromotive force drops in the different phase-windings embody the opposite phase-sequence from the electromotive forces of the respective windings, of means for, in effect, reversing the direction of phase-sequence of said last-named winding electromotive forces without affecting the phase-sequence of said drops.

5. The combination with a polyphase dynamo-electric machine wherein certain of the phase-windings function as motor windings and certain other phase-windings function as generator windings, whereby the electromotive force drops in said windings have the opposite phase-sequence from the electromotive forces of said windings, of means for, in effect, reversing the phase-sequence of said last-named winding electromotive forces.

6. The combination with a phase-converter of the dynamo-electric type, of means for, in effect, reversing the phase-sequence of the generated electromotive forces thereof without reversing the phase-sequence of the electromotive force drops in the windings thereof.

7. In a system of distribution, the combination with a single-phase winding, of a polyphase winding, a polyphase phase-converter, connections from certain terminals of said polyphase winding through phase windings of said converter to the terminals of said single-phase winding, and other connections from the remaining polyphase terminals through the remaining phase-con-

verter windings to intermediate points in said single-phase winding, said connections being so arranged that the electromotive force of said single-phase winding produces the result of reversing the phase-sequence of the output electromotive forces of said phase-converter without reversing the phase-sequence of the drops therein.

8. In a system of distribution, the combination with a single-phase winding, of a three-phase winding, a three-phase, phase converter having distinct phase-windings, connections from two terminals of said three-phase windings through two windings of said phase-converter to the terminals of said single-phase winding, respectively, and a connection from the remaining terminal of said three-phase winding through the remaining converter winding to an intermediate point in said single-phase winding, the direction of connection and the electromotive force of said single-phase winding being such that said electromotive force produces the effect of reversing the phase-sequence of the electromotive forces of said converter without reversing the phase-sequence of the electromotive force drops in the converter winding.

9. The combination with a phase-converter having non-interconnected windings, of a load circuit adapted to close an operating circuit through said converter, and means for providing an auxiliary operating circuit to maintain said converter in operation when said load circuit is open.

10. The combination with a transformer having a primary winding connected to a source of alternating current and having main and auxiliary secondary windings, of a phase-converter having independent windings connected to said main secondary winding, a load circuit connected to close an operating circuit through said converter, and means whereby, if said load-circuit is disconnected, said auxiliary secondary winding is connected to close an operating circuit through said converter, whereby said converter is maintained in operation.

11. In a system of distribution, the combination with a single-phase winding, of a polyphase winding, a polyphase, phase-converter, connections from certain terminals of said polyphase winding through phase-windings of said converter to the terminals of said single-phase winding, other connections from the remaining polyphase terminals through the remaining phase-converter windings to intermediate points in said single-phase winding, said connections being so arranged that the electromotive force of said single-phase winding produces the effect of reversing the phase-sequence of the output electromotive forces of said phase-converter without reversing the phase-sequence of the drops therein, and additional means for interchanging energy directly between said polyphase winding and the windings of said phase-converter.

12. In a system of distribution, the combination with a single-phase winding, of a polyphase winding, a polyphase phase-converter, connections from certain terminals of said polyphase winding through phase-windings of said converter to the terminals of said single-phase winding, other connections from the remaining polyphase terminals to intermediate points in said single-phase winding, said connections being so arranged that the electromotive force of said single-phase winding produces the effect of reversing the phase-sequence of the output electromotive forces of said phase-converter without reversing the phase-sequence of the drops therein, means for interchanging energy directly with certain of the windings of said converter, respectively, and means for connecting said means to said polyphase winding in the phase sequence of said converter windings, whereby wattless currents may flow between said converter and said polyphase winding for power-factor control.

13. In a system of distribution, the combination with a single-phase winding, of a three-phase winding, a three-phase, phase-converter having distinct phase windings, connections from two terminals of said three-phase winding through two windings of said phase-winding, respectively, to the terminals of said single-phase winding, a connection from the remaining terminal of said three-phase winding through the remaining converter winding to an intermediate point in said single-phase winding, the direction of connection and the electromotive force of said single-phase winding being such that said electromotive force produces the effect of reversing the phase-sequence of the electromotive forces of said converter without reversing the phase-sequence of the electromotive force drops in the converter winding, and means for interchanging energy between each converter phase-winding connected to a single-phase terminal and the phase of said three-phase winding connected to the other single-phase terminal, whereby wattless-energy interchange may take place between said converter and said polyphase winding.

14. The method of balancing an unbalanced polyphase system comprising a major balanced polyphase component having phase-sequence in a given direction and a minor balanced polyphase component having the opposite phase-sequence, which comprises, in effect, reversing the phase-sequence of said major component without reversing the phase-sequence of said minor component, whereby said two components are caused to

have the same phase-sequence and coalesce to produce a single substantially balanced polyphase resultant.

15. The method of balancing the output electromotive forces of a phase-converter wherein the winding electromotive forces have one phase-sequence and the drop electromotive forces have the other phase-sequence which comprises, in effect, reversing the phase-sequence of said winding electromotive forces without affecting the phase-sequence of said drop electromotive forces.

16. An electrical system including, in combination, a three-phase translating device, two single-phase translating devices, said single-phase devices developing electromotive forces of the same frequency, a three-phase dynamo-electric machine having a damper winding, and connections for connecting said three-phase machine in series-circuit relation between said three-phase translating device and said single-phase translating devices, said connections being made in such manner that said single-phase electromotive forces are in the proper directions for combining with the three-phase electromotive forces of said machine to produce a resultant three-phase electromotive force having the opposite phase-sequence.

17. An electrical system including, in combination, a three-phase translating device, a single-phase transformer including two winding elements, a three-phase dynamo-electric machine having a damper winding, and connections for connecting said three-phase machine in series-circuit relation between said three-phase translating device and said single-phase winding elements, said connections being made in such manner that the single-phase electromotive forces are in the proper directions for combining with the three-phase electromotive forces of said machine to produce a resultant three-phase electromotive force having the opposite phase-sequence.

18. An electrical system including, in combination, a three-phase translating device, a single-phase transformer winding provided with three taps dividing the same into two winding elements, a dynamo-electric machine having non-interconnected three-phase primary windings and a damper winding, and connections for connecting the three primary windings severally in series-circuit relation between the respective transformer taps and the three-phase translating device.

19. The combination with a line having two sets of polyphase electromotive forces of like phase-number but of opposite phase-sequence, of a polyphase translating device having substantially balanced currents, a dynamo-electric machine having polyphase primary windings and damper windings, and means for associating said primary windings in series relation to said line and said translating device, said primary and damper windings having a relative rotation at substantially synchronous speed in such direction that the electromotive forces generated in said primary windings are opposite in phase sequence to the electromotive forces of said translating device.

20. The combination with a line having two sets of polyphase electromotive forces of like phase-number but of opposite phase-sequence, of a polyphase translating device having substantially balanced currents, a dynamo-electric machine having polyphase primary windings and damper windings, means for associating said primary windings in series relation to said line and said translating device, said primary and damper windings having a relative rotation at substantially synchronous speed in such direction that the electromotive forces generated in said primary windings are opposite in phase sequence to the electromotive forces of said translating device, and means for supplying said machine with a variable direct-current excitation.

21. The combination with a line having two sets of polyphase electromotive forces of like phase-number but of opposite phase-sequence, of a polyphase translating device having substantially balanced currents, a dynamo-electric machine having polyphase primary windings and damper windings, means for associating said primary windings in series relation to said line and said translating device, said primary and damper windings having a relative rotation at substantially synchronous speed in such direction that the electromotive forces generated in said primary windings are opposite in phase sequence to the electromotive forces of said translating device, and means for disconnecting said translating device and operating said machine with a shunt connection across said line.

22. The combination with a line having two sets of polyphase electromotive forces of like phase-number but of opposite phase-sequence, of a polyphase translating device having substantially balanced currents, a dynamo-electric machine having polyphase primary windings and damper windings, means for associating said primary windings in series relation to said line and said translating device, said primary and damper windings having a relative rotation at substantially synchronous speed in such direction that the electromotive forces generated in said primary windings are opposite in phase sequence to the electromotive forces of said translating device, and switching means for disconnecting said translating device and providing a closed circuit for at least two of the phases of said polyphase primary winding.

23. The combination with a line having two sets of polyphase electromotive forces of like phase-number but of opposite phase-sequence, of a polyphase translating device having substantially balanced currents, a dynamo-electric machine having polyphase primary windings and damper windings, means for associating said primary windings in series relation to said line and said translating device, said primary and damper windings having a relative rotation at substantially synchronous speed in such direction that the electromotive forces generated in said primary windings are opposite in phase sequence to the electromotive forces of said translating device, and means for maintaining the rotation of said machine when said translating device is disconnected.

In testimony whereof, I have hereunto subscribed my name this 28th day of Nov., 1917.

CHARLES LE G. FORTESCUE.