R. E. HELLMUND.

PHASE CONVERTER BALANCING SYSTEM.

APPLICATION FILED SEPT. 28, 1917.

1,365,691. Patented Jan. 18, 1921.

6 SHEETS—SHEET 1.

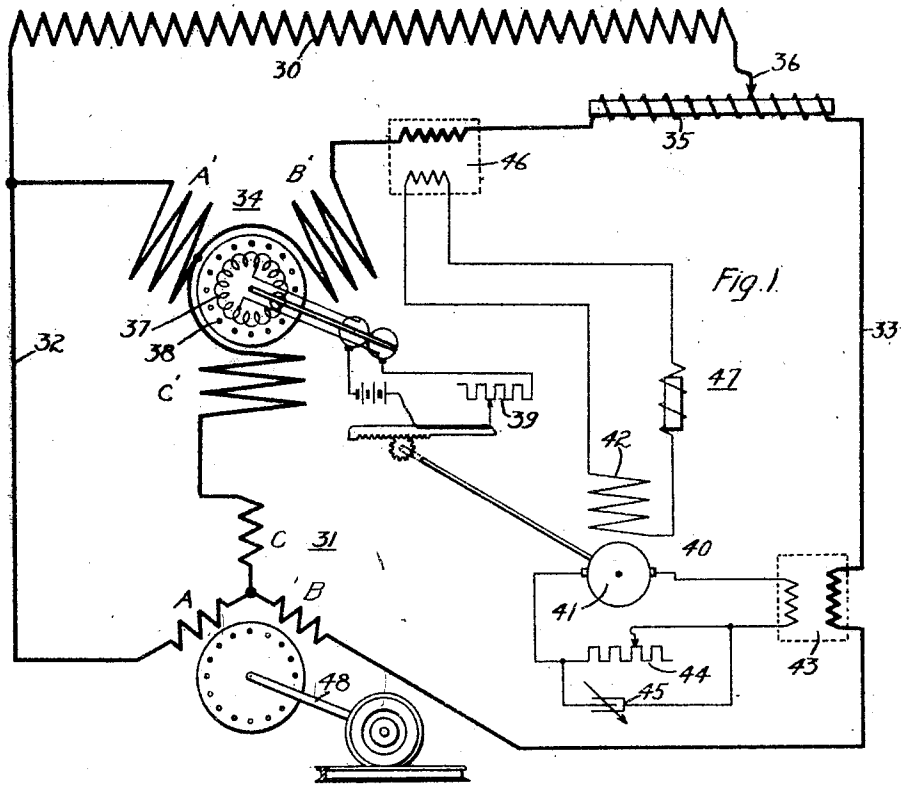


Fig. 1.

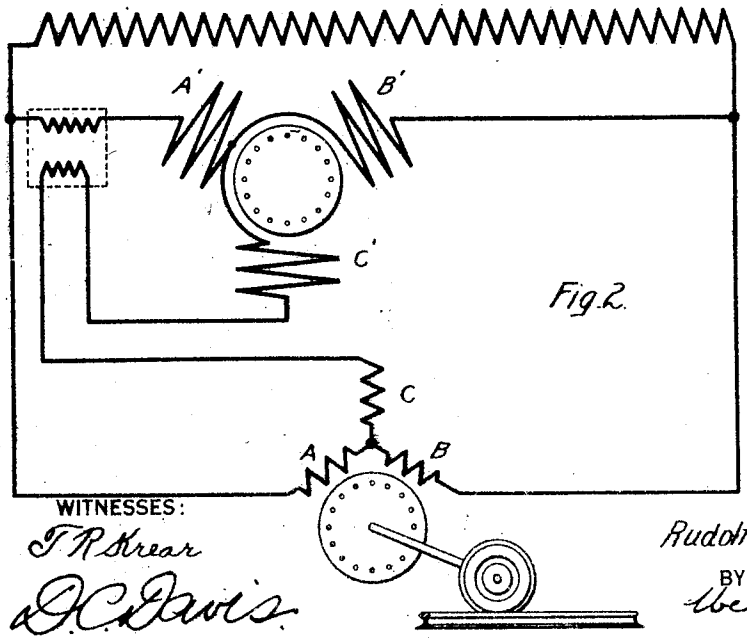


Fig. 2.

WITNESSES:

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D. C. Davis

INVENTOR

Rudolf E. Hellmund

BY

Overley & Carr

ATTORNEY

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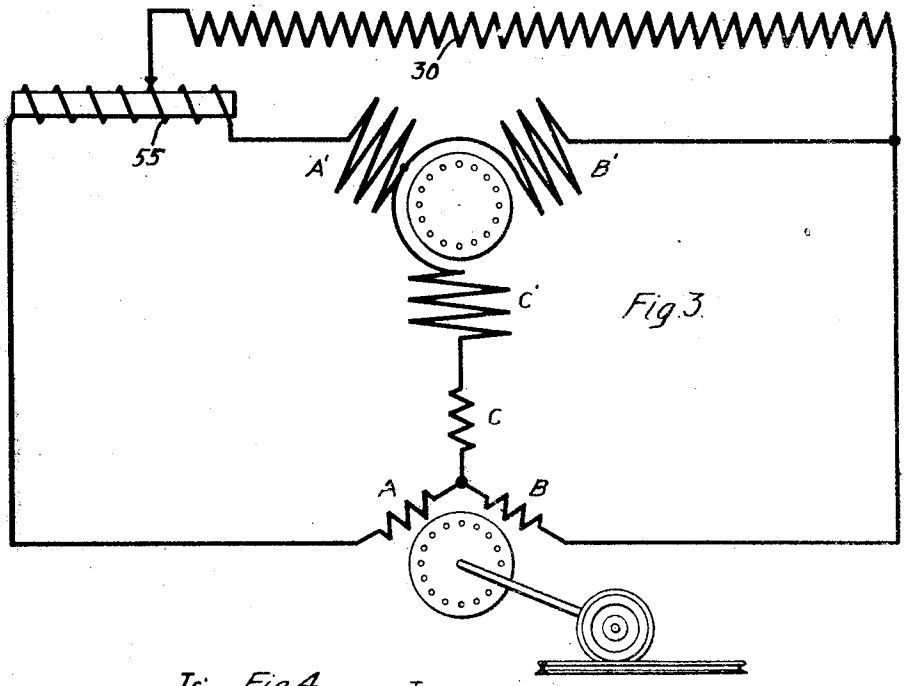


Fig. 3.

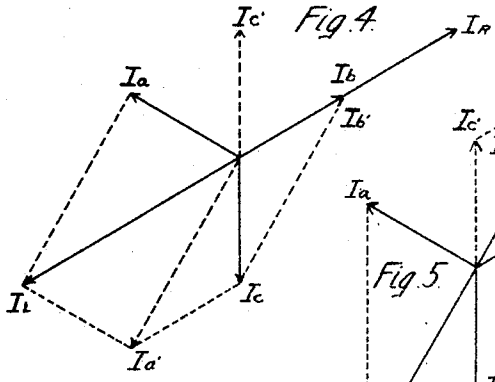


Fig. 4

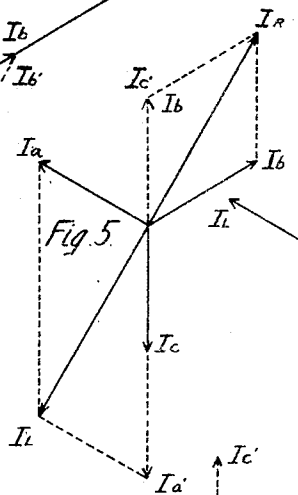


Fig. 5

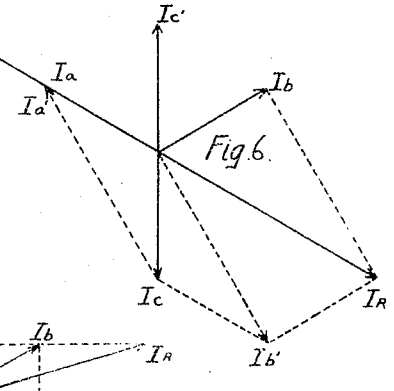


Fig. 6.

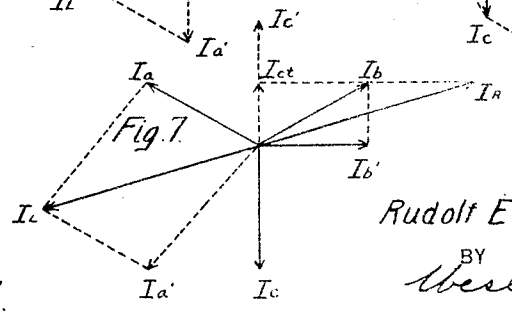


Fig. 7.

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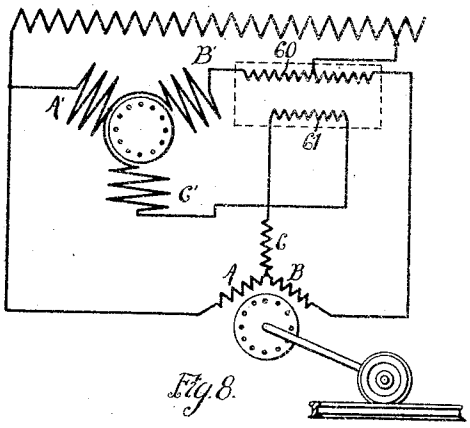


Fig. 8.

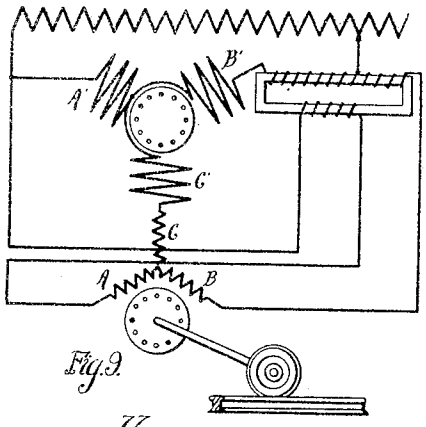


Fig. 9.

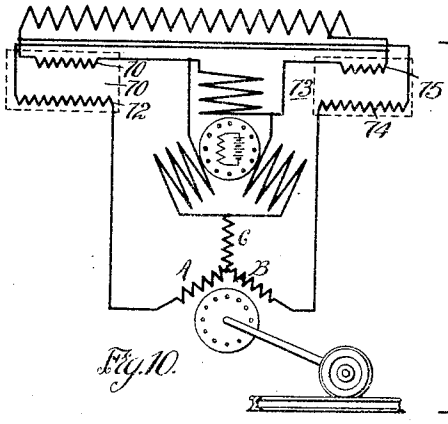


Fig. 10.

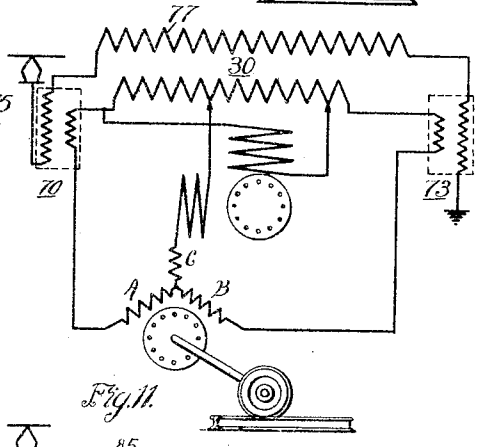


Fig. 11.

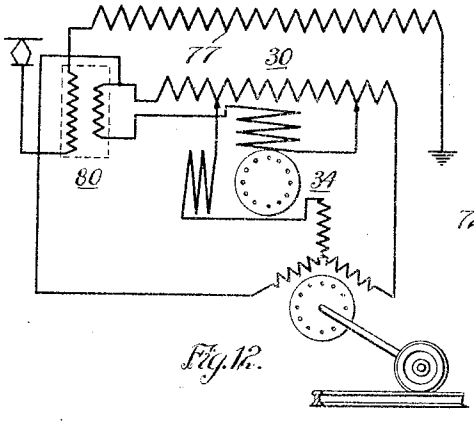


Fig. 12.

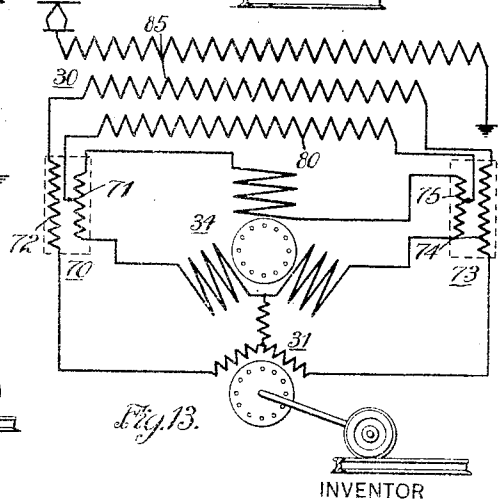


Fig. 13.

WITNESSES:

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6 SHEETS—SHEET 4.

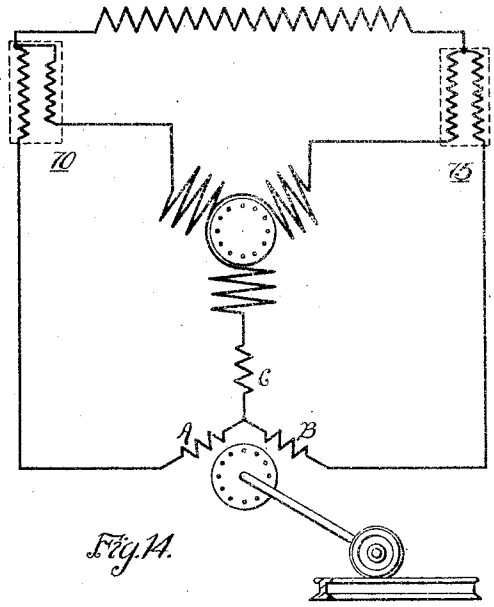


Fig. 14.

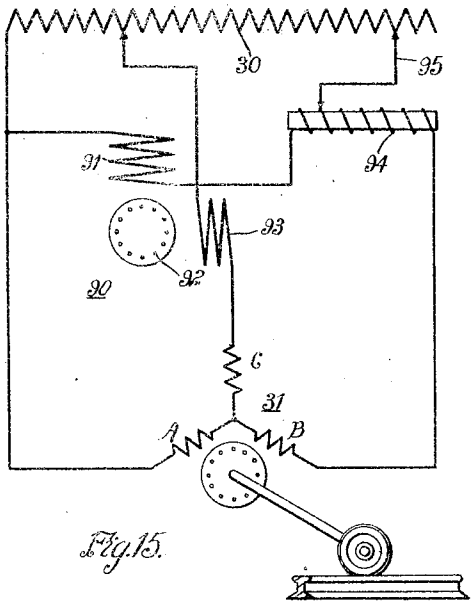


Fig. 15.

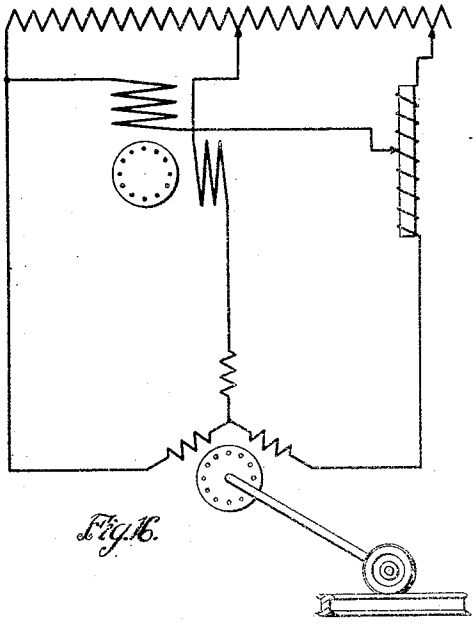


Fig. 16.

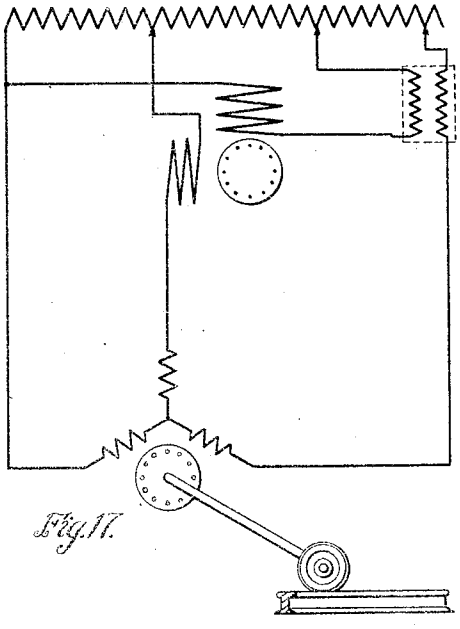


Fig. 17.

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6 SHEETS—SHEET 5.

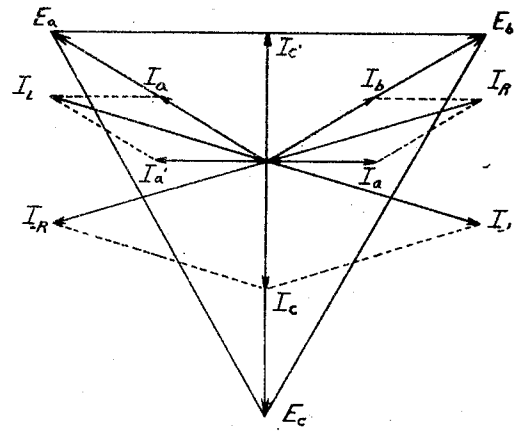


Fig. 18.

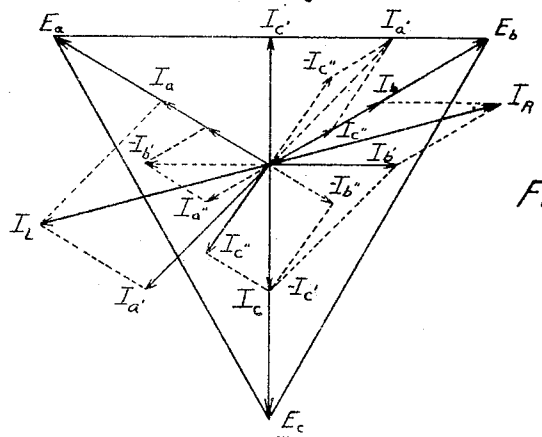


Fig. 20

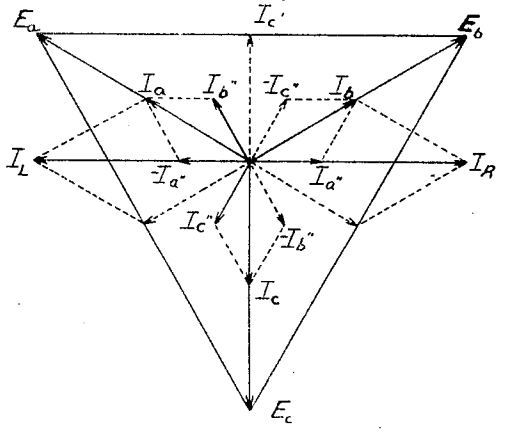


Fig. 19

WITNESSES:

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PHASE CONVERTER BALANCING SYSTEM.

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1,365,691.

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6 SHEETS—SHEET 6.

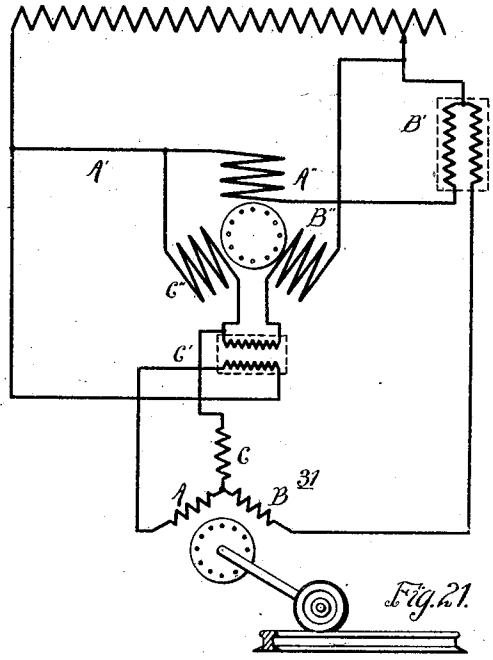


Fig. 21.

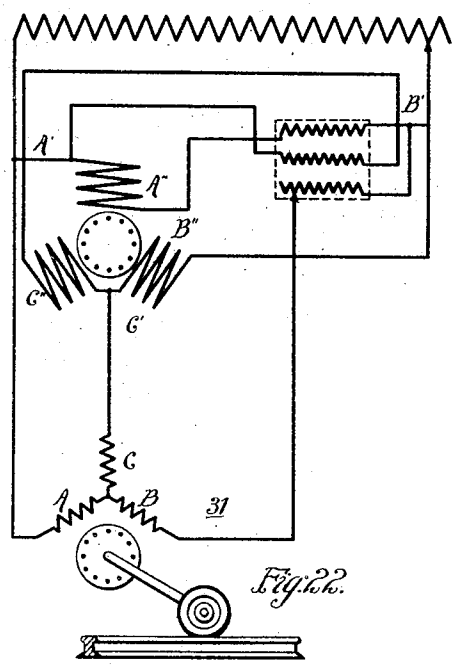


Fig. 22.

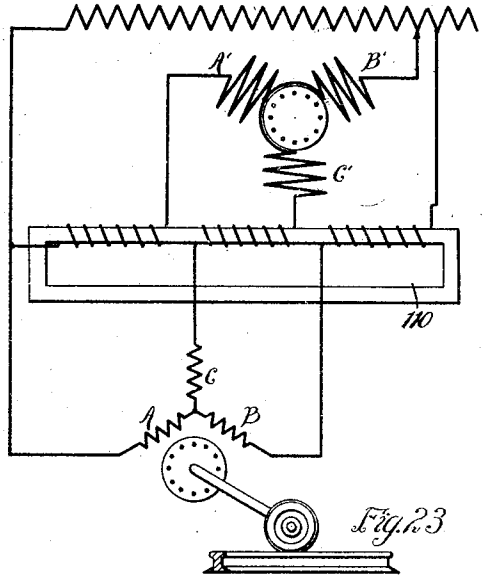


Fig. 23

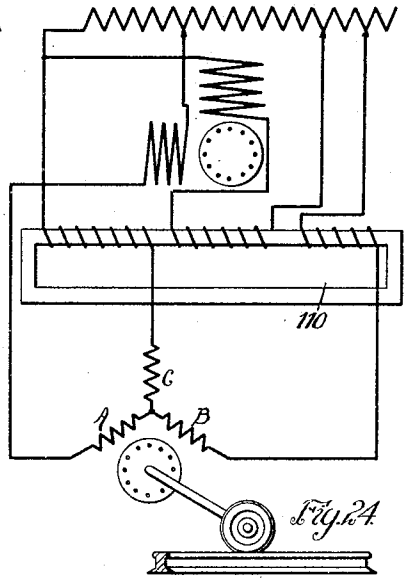


Fig. 24

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UNITED STATES PATENT OFFICE.

RUDOLF E. HELLMUND, OF SWISSVALE, PENNSYLVANIA, ASSIGNOR TO WESTINGHOUSE ELECTRIC & MANUFACTURING COMPANY, A CORPORATION OF PENNSYLVANIA.

PHASE-CONVERTER BALANCING SYSTEM.

1,365,691. Specification of Letters Patent. Patented Jan. 18, 1921.

Application filed September 28, 1917. Serial No. 193,695.

To all whom it may concern:

Be it known that I, RUDOLF E. HELLMUND, a citizen of the German Empire, and a resident of Swissvale, in the county of Allegheny and State of Pennsylvania, have invented a new and useful Improvement in Phase-Converter Balancing Systems, of which the following is a specification.

My invention relates to balancing means for phase-converter systems, and it has for its object to provide a system of the character designated whereby, when a polyphase circuit is arranged to derive energy from a single-phase circuit through the instrumentality of a phase-converter, the different phases of said polyphase circuit may be maintained in substantial balance, irrespective of the ohmic and reactance drops in the phase-converter.

Another object of my invention is to provide a system of the character designated whereby, when a single-phase circuit derives energy from a polyphase circuit, said energy may be derived uniformly from the different phases of the polyphase circuit, thus preventing unbalancing and distortion of the respective voltages and currents therein.

In the accompanying drawing, Figure 1 is a simplified diagrammatic view of a single-phase system and a polyphase system, together with a phase-converter and auxiliary apparatus, embodying a preferred form of my invention; Figs. 2, 3, 8 to 17, inclusive, 21, 22, 23 and 24 are simplified diagrammatic views illustrating modifications of the system shown in Fig. 1; Figs. 4 to 7, inclusive, are vector diagrams illustrative of the operation of systems of Figs. 1 to 3, inclusive, and Figs. 18, 19 and 20 are vector diagrams illustrating the operation of the systems of Figs. 15, 16 and 17, respectively.

In U. S. Patent No. 1,280,007, issued to the Westinghouse Electric & Manufacturing Company, September 24, 1918, on an application filed by Charles Le G. Fortescue, is disclosed and claimed a phase-converting system wherein a polyphase circuit is energized from a single-phase circuit, one phase of the polyphase circuit deriving its energy directly from said single-phase circuit and the remaining phases of said polyphase circuit being energized by the composition of a portion of the electromotive force of said single-phase circuit with the tertiary voltage of a phase-converter. In a system of this character, the effect of an increase in load is to increase the ohmic and inductive drops within said phase-converter, thus modifying the magnitude and phase location of the tertiary voltage and distorting the electromotive forces of the polyphase circuit. In accordance with the above-mentioned disclosure of the Fortescue application, transformers are interposed between the supply conductors leading to the converter and those leading directly to the load whereby, upon an increase in the load current, a boosting electromotive force is imposed upon the phase-converter, tending to raise the tertiary voltage thereof and thus neutralizing the effect of the ohmic and inductive drops therein. In the systems of the Fortescue disclosure, the transformers have a one-to-one ratio and serve to produce the desired balancing effect only when the power-factors of the supply system and of the polyphase circuit are substantially the same. The conductors in which said transformers are inserted are so chosen that the primary and secondary currents of each transformer are in substantial phase opposition, whereby the flux thereof is substantially zero, under balanced operating conditions.

In accordance with the present invention, I provide means whereby, by the proper adjustment of the size and ratios of transformation of the auxiliary transformers and by their proper location, I am enabled to produce a similar balancing effect to that disclosed in the Fortescue application when the power-factors of the supply circuit and of the polyphase circuit are different, as is usually the case in commercial practice. In all cases, the auxiliary transformers employed by me are so designed and disposed that the primary currents thereof are in phase opposition and thus, said transformers exert no deleterious influence upon the power-factor of the circuit.

Referring to the drawing for a more detailed understanding of my invention, I show a source of single-phase alternating current at 30 in Fig. 1, such, for example, as the secondary winding of a supply transformer (not shown). Energy is supplied from the source 30 to a polyphase circuit, shown as comprising a polyphase railway propulsion motor 31 of the induction type, by means of supply mains 32 and 33 and a

phase-converter 34 of the dynamo-electric type. The primary winding of the motor 31 is shown as of the three-phase, Y-connected type and the phase windings thereof are for convenience designated as A, B and C. In like manner, the phase-converter 34 has a three-phase Y-connected stator winding, the respective phase-windings of which are designated for convenience as A′, B′ and C′. The phase-windings A and A′ are connected to be energized from the left-hand terminal of the source 30 and, in like manner, the phase windings B and B′ are arranged to be energized from the right hand terminal of the source 30, said phase windings being connected to the respective outside terminals of an auto-transformer 35, and the right-hand terminal of the source 30 being connected to an adjustable tap 36 on the winding of said auto-transformer 35. The phase winding C′ of the converter 34 operates as the tertiary winding and is connected to supply energy directly to the phase-winding C of the motor 31.

Under ordinary operating conditions, the power factor of the single-phase circuit is substantially unity or said power-factor may be rendered capacitative in nature by virtue of the synchronous operation of the converter 34, produced by direct-current excitation, as in an auxiliary rotor winding 37, employed in addition to the ordinary short-circuited winding 38. Unless special phase advancing means are employed in connection with the motor 31, the power-factor of the polyphase circuit will be lagging in nature and thus, there will be a marked phase displacement between the currents in the two circuits.

With different loads, the power-factor of the motor 31 varies but it is nevertheless desirable, for the successful operation of my invention, that the phase-displacement or the difference in power-factor between the two circuits be substantially constant. To this end, the winding 37 is energized through a rheostat 39 which is subject to control, as by an auxiliary motor 40 comprising an armature 41 and a field winding 42. The armature 41 is energized from a current transformer 43 inserted in the supply lead 33 of the phase winding B through a non-inductive or capacity circuit provided by an adjustable resistor 44 and, if desired, by an adjustable capacitance 45 disposed in parallel relation thereto.

In like manner, the field winding 42 is energized from a current transformer 46 inserted in the lead to the phase winding B′ through an inductive circuit comprising a reactor 47.

The operation of auxiliary apparatus thus described is as follows. Under normal operating conditions, as will hereinafter be pointed out, the currents in the phase windings B and B′ are in phase with each other and the currents supplied to the armature 41 and to the field winding 42 are, therefore, in substantial quadrature to each other, producing no torque in the auxiliary motor 40. If the power-factor of the motor 31 changes, because of load changes, there is a relative shifting in the currents supplied to said motor and to the phase-converter, producing a transfer of energy to the motor 40 for the operation thereof. The rheostat 39 is thus adjusted to alter the direct-current excitation of the converter 34 and to readjust the power-factor of the supply system to maintain the desired phase-displacement between the currents of the single-phase and polyphase circuits.

Having thus described the arrangement of a system embodying my invention, the balancing operation therein is as follows, particular reference being had to the vector diagram of Fig. 4.

Assuming that it is desired to maintain the power factor of the polyphase or motor circuit so that the current thereof lags 30° with respect to the current of the single-phase or supply circuit, the currents supplied from the right and left-hand terminals of the single-phase source may be indicated by equal and opposite vectors I_R and I_L, respectively, and the converter currents by vectors I_a', I_b' and I_c', respectively. The current supplied to the motor 31 may be indicated by vectors I_a, I_b and I_c, respectively, said vectors being equal and substantially 120° apart. The effect of the assumed 30° phase displacement is to throw the vector I_b into alinement with the vector I_R, as may be deduced by comparison with Fig. 2 of the aforementioned Fortescue application.

Since the vector I_R is the sum of the vectors I_b and I_b', then the vector I_b' must also be in alinement with I_R. The vector I_c' is obviously in phase opposition to the vector I_c, and the vector I_a' may be derived by the composition of the vectors I_b' and I_c'. The transformer 35 inductively interlinks the leads of the phase windings B and B′, as shown.

If it be assumed that there is an increase in the motor load, all the vectors in Fig. 4 would tend to increase in magnitude but the vectors I_c and I_c' would not increase in proportion to the remaining vectors because of the ohmic and inductive drops in the converters. The flow of current through the right-hand half of the transformer 35 to the phase winding B, however, produces a boosting electromotive force in the left-hand half of said auto-transformer, thus increasing the electromotive force applied to the converter 34 and compensating for the drops therein, producing proportional increase in the vectors I_c and I_c'. From the vectorial

point of view, the increase in the vector I_b causes a like increase in the vector I_b' and this, in turn, causes an increase in the vectors I_c and I_c', without disturbing the relative phase relation of the currents in the single-phase and polyphase circuits.

It will be noted that, under balanced operation, with the currents I_b and I_b' inversely proportional to the number of turns to the right and to the left of the tap point 36 of the transformer 35, there is flux neutralization within said transformer, and its winding is, therefore, substantially non-inductive.

While the operation of the foregoing system has been discussed during motor operation, a similar action is present during regeneration or, in other words, when the machine 31 is driven as a generator, as by a car axle 48, energy is returned to the system 30. Under these conditions, the energy drain on each phase of each machine is substantially the same.

If it be assumed that the motor currents lag 60° more behind their applied electromotive force than the supply current lags behind its electromotive force, necessitating, in most cases, that the current in the supply circuit lead its electromotive force by an appreciable amount, the current relations will be as indicated in Fig. 5. The vector I_b' is moved into alinement with the vector I_c', moving the vector I_a', also in alinement with the vector I_c. Thus, a transformer having the desired phase opposition in its primary and secondary circuits and, at the same time, serving to produce a booster effect in one of the converter-supply leads from one of the motor-supply leads may be employed to operate with the currents I_c and I_a' or with the currents I_c and I_b', it obviously being useless to inductively interlink circuits conveying the currents I_c and I_c'.

In Fig. 2, I have shown the supply lead to the phase winding A′ inductively interlinked with the supply lead to the phase winding C, whereby, an increase in the current flowing to the phase winding C boosts the voltage supplied to the converter and serves to maintain the vector I_c symmetrical in size and location with respect to the vectors I_a and I_b.

If it be assumed that the angle of lag of the single-phase supply circuit is 30° more than that of the polyphase motor circuit, a condition which approximately exists with asynchronous phase converters, the phase relations will be as indicated in Fig. 6. The vectors I_a and I_a' are in line with the vectors I_R and I_L and thus, the desired inductive relationship may be established between any conductors conveying these currents. Thus, in the system of Fig. 3, an auxiliary transformer 55 is shown, inductively interlinking the supply lead to the phase-winding A with that to the phase winding A′. Obviously, transformers might be employed having their primary windings inserted in the mains from the source 30, said mains carrying the currents I_R and I_L, respectively; appropriate ratios of transformation being employed to produce the desired boosting effects.

Up to this point, only those cases have been discussed wherein motor-supply currents and phase-supply currents were in phase opposition, whereby the desired non-inductive action of the booster transformer under balanced conditions might be obtained. A similar action may be produced, however, with other phase relations between the single-phase currents and the polyphase currents, as indicated, for example, in connection with Figs. 7 and 8. If it be assumed that the single-phase supply current I_R lags 16° less behind its voltage than the motor currents lag behind their voltage, the vector diagram is as shown in Fig. 7. An auto transformer 60 inductively interlinks the supply leads of the phase windings B and B′, each winding thereof having, for example, 100 turns. An auxiliary winding 61 is also inductively associated therewith and has, for example, 50 turns. Under balanced operating conditions, as shown in Fig. 7, the sum of the vectors I_b' and I_{ct} is equal to the vector I_b, I_{ct} being shown as one-half the vector I_c' because the winding 61 contains only one-half as many turns as the remaining windings of the transformers, the current I_c thus exerting one-half the transformer effect of the other currents. If the motor current increases, the current I_b increases, producing boosting effects upon the currents I_{ct} and I_b' and producing the desired compensation of the electromotive forces.

Fig. 9 shows a system similar to that of Fig. 8, the supply lead to the phase winding A being inductively interlinked with the supply leads to the phase windings B and B′ as shown.

In the aforementioned Fortescue application, it is pointed out that, by inductively interlinking each direct supply lead to the polyphase circuit with a phase-converter supply lead, relatively displaced therefrom in phase, balancing might be effected with the use of equal transformers having 1 to 1 ratios of transformation when the power factors of the single-phase and of the polyphase circuits were respectively equal. By suitable modification of this system in the alteration of the relative magnitude of the transformers and of their respective ratios of transformation, a similar balancing action may be obtained under the conditions of different power-factor in the single-phase and polyphase circuits, as obtained in commercial practice.

I have discovered that, in systems of the character above described, the relative phase rotation and converter rotation must be

taken into consideration when the impedance drops in the two leads from the single-phase source to the primary converter windings are calculated. I find by experiment that the drops in the two leads are different, and that the difference depends upon the relative rotation of the machine and phases and that, therefore, compensating means must be supplied which will take into consideration this unequality of impedance drop in the two leads and neutralize the same. One method of so compensating correctly for the unequal drops is by the employment of transformers of unequal sizes in the two leads.

Fig. 10 illustrates a system of this character, being particularly adapted for use with the inductive motor power factor and with capacitative converter power-factor, as is usual with synchronous phase-converters. Thus, in the system of Fig. 10, a supply lead from the right-hand terminal of the source 30 to the phase winding A is inductively interlinked with a converter supply lead from the left-hand terminal of the source 30, by means of a transformer 70. In like manner, a lead from the left-hand terminal of the source 30 to the phase winding B is inductively interlinked with a phase-converter lead to the right-hand terminal of the source 30 through an auxiliary transformer 73. The transformer 70 is preferably larger than the transformer 73, assuming counter-clockwise phase rotation, and comprises two windings 71 and 72, the winding 71 being inserted in the motor lead and the motor 72 being inserted in the converter lead. For the best effect, under the assumed conditions, the winding 72 should comprise more turns than the winding 71. In like manner, the auxiliary transformer 73 comprises windings 74 and 75 associated respectively with the motor and converter leads, the winding 74 comprising more turns than the winding 75. The operation of the system thus described is, in general, similar to that of the foregoing systems, the effect of an increase in the motor current being to slightly boost the voltage applied to the motor, thus compensating for drops within the converter.

The system of Fig. 11 is, in many respects, similar to that of Fig. 10 except that the auxiliary transformers 70 and 73 inductively interlink the supply leads of the primary winding 77 of the transformer 30 with the direct supply leads to the motor, instead of being disposed as in Fig. 10. Thus, an increase in the motor current slightly boosts the voltage supplied to the primary winding of the transformer 30, thus raising the voltage supplied to the primary winding of the phase-converter.

In the system of Fig. 12, an auxiliary transformer 80 is employed, inductively interlinking one supply lead of the primary winding 77 of the supply transformer with one of the primary supply leads of the phase-converter 34.

In the system of Fig. 13, the supply transformer 30 is provided with two secondary windings 85 and 86, the former being employed for supplying the motor 31 and the latter being employed to energize the phase-converter 34. Two auxiliary transformers 70 and 73 are provided having windings 71, 72, 74 and 75, as before described. The windings 72 and 74 are inserted in the supply leads which go directly to the motor 31, and the windings 71 and 75 are inserted, respectively, between pairs of phase windings in a delta-connected phase-converter 34, the derived phase being connected at the remaining vertex of the delta thus established. The terminals of the phase-converter supply winding 86 are connected respectively to adjustable points in the transformer windings 72 and 75, whereby the relative voltages impressed upon the various component parts of the converter stator winding may be adjusted as required by different relative power factors in the single-phase and polyphase circuits. In the system of Fig. 13, it is preferable that the transformer 70 be larger than the transformer 73, for best results, assuming counter-clockwise rotation.

The system of Fig. 14 is, in many respects, similar to that of Fig. 10, but differs therefrom in that the transformer 70 inductively interlinks the two supply leads from the left-hand terminals of the source 30 to the converter and motor, respectively, and, in like manner, the transformer 73 inductively interlinks the two terminals of the right-hand source 30. The relative size and the ratios of transformation of the transformers 70 and 73 may be adjusted to produce balancing under different relative power factors, as before described.

The foregoing disclosures have shown the use of converters of the three-phase type but the general principles, herein set forth, are further applicable to systems embodying phase converters of the T-connected type, as follows.

Thus, in Fig. 15, I show a T-connected phase-converter 90 embodying a primary winding 91, a secondary winding 92 and a tertiary winding 93, employed for supplying energy of displaced phase to a polyphase motor 31, as before. An auto-transformer 94 is employed for inductively interlinking the converter and motor leads supplied from the right-hand terminals of the source 30. Said source is connected to said auto-transformer through an adjustable tap member 95, whereby the booster effect of the increased motor current upon the primary impressed voltage of the converter may be modified.

Designating the respective phase windings of the motor 31 as A, B and C, respectively, for convenience in vector discussion and similarly designating the two phase windings of the converter as A′ and C′, attention is directed to the vector diagram of Fig. 18 for an understanding of the operation of the system disclosed in Fig. 16, the vectors I_a, I_b and I_c indicating, respectively, the currents in the phase windings A, B and C of the motor 31, said vectors being of equal length and having a relative phase displacement of 120 degrees. The current in the tertiary winding 23 may be represented by the vector $1_c'$, being in phase opposition to the vector I_c, because of the fact that an inwardly flowing current in the motor is outwardly flowing in the converter and vice versa. The current in the primary winding 91 is indicated by the vector I_a', in quadrature to the vector I_c' because of the effect of the phase converter. The current flowing from the left-hand terminal of the source 30 is the sum of the currents I_a and I_a' and may be indicated by the vector I_L. The current flow between the primary winding 91 and the right-hand terminal of the source 30 may be represented by the vector $-I_a'$, and the sum of this current with the current I_b flowing in the phase winding B constitutes the current flowing from the right-hand terminal of the source 30. Thus, the current flow from said right-hand terminal may be indicated by the vector I_R. It will be noted that there is a difference in the phase of the currents I_R and I_L but said currents, in conjunction, are in alinement with the vector I_a', whereby there would be produced the desired phase opposition in the phase-transformer 94 to enable said transformer to perform the desired boosting effect under load change and, furthermore, causing said transformer to be without flux under conditions of load balance, as in the previously disclosed systems.

If the angle of lag of the line current be substantially 14° less than indicated in Fig. 18, a condition which is more readily attained in converter systems, the vectors I_b, I_{-R} and I_a' are in alinement with each other and mutually inductive interlinkages may be established between the corresponding leads to produce a balancing effect, as shown in Figs. 15, 16 and 17.

If the angle of phase-lag of the converter be increased substantially 14°, the vectors I_a, I_{-L} and I_a' are brought into alinement, permitting inductive interlinkage of the leads carrying currents corresponding respectively to these vectors.

Fig. 19 illustrates the vector relation in a system embodying a delta-connected converter under the assumption that the power-factor and the motor-factor are the same. The corresponding circuit diagram is shown in Fig. 21, the phase windings of the motor 31 being designated, respectively, as A, B and C, the supply leads of the delta-connected converter being designated as A′, B′ and C′, respectively, as said leads convey currents corresponding to the similarly designated star-currents heretofore discussed, the phase windings of the converter itself being designated as A″, B″ and C″, respectively. In the vector diagram of Fig. 19, the motor currents are indicated by the equally-spaced vectors I_a, I_b and I_c. The currents flowing in the right and left supply leads are in quadrature to the derived currents I_c' and may therefore be indicated by the vectors I_R and I_L, respectively. The current in the phase winding A″ is in phase with the current of the source 30 and may be designated by the vectors I_a'' and $-I_a''$, said vectors being in alinement with the vectors I_R and I_L. The currents in the phase windings B″ and C″ are displaced 120° with respect to the currents in the phase winding A″ and may, therefore, be designated by the vectors I_b'' and I_c'', respectively.

If now it be assumed that the angle of lag of the line current is 15° less than that of the motor current, the conditions will be altered as shown in Fig. 20. The vectors I_b and I_a'' are brought into alinement with each other and also the vectors I_a and I_b''.

Mutual inductance devices may therefore be provided between the corresponding leads, as indicated in Fig. 21, to produce the desired balancing action when conditions are disturbed, said means being inactive under conditions of load balance.

Under different relative phase relations of the motor current and converter current, it may be desirable to further modify the connections, as indicated in Fig. 22, when employing a delta-connected phase converter. The supply lead to the converter phase winding A″ is inductively interlinked with that of a phase-winding C″, thus producing the effect of a transformer winding energized by current mid-way in phase between the currents of the phase windings A″ and C″, respectively, and an additional winding is employed which is inserted in the supply lead to the motor phase B, thus producing an effect similar to that obtained by the use of a transformer inductively interlinking the supply lead to the phase winding B with the supply lead to the phase winding A′ of a system employing a star-connected converter.

In the system of Fig. 23, the supply lead for the phase winding A′ of the converter is inductively interlinked with supply lead for the motor phase winding B and said windings together are inductively interlinked with the supply winding for the phase winding C, all by a transformer 110. By this

means, an increase in the motor current flowing to the phase-winding B boosts the voltage supplied to the converter phase winding A′ and further boosts the tertiary voltage derived from said converter and supplied to the motor 31.

In the system of Fig. 24, a T-connected, phase-converter is employed and a single transformer 110 inductively interlinks the supply lead for the motor phase winding B and that for the motor phase winding A with the supply lead for the converter primary winding, thus producing a similar effect to some of the former figures wherein two separate transformers were employed for performing a single function.

While I have disclosed my invention in a plurality of modifications, it is not so limited but is susceptible of various minor changes 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 as are specifically set forth in the appended claims.

I claim as my invention:

1. In a converting system, the combination with a single-phase circuit, of a polyphase circuit, connections from the mains of said single-phase circuit to certain mains of said polyphase circuit, a phase-converter, connections for inserting said phase-converter between said single-phase circuit and the remaining mains of said polyphase circuit, and means for inductively interlinking certain direct supply leads from said single-phase circuit to said polyphase circuit with certain leads from said single-phase circuit to said converter, respectively, comprising transformers of unequal size.

2. In a converting system, the combination with a single-phase circuit, of a polyphase circuit, connections from the mains of said single-phase circuit to certain mains of said polyphase circuit, a phase-converter, connections for inserting said phase-converter between said single-phase circuit and the remaining mains of said polyphase circuit, and means for inductively interlinking certain direct supply leads from said single-phase circuit to said polyphase circuit with certain leads from said single-phase circuit to said converter, respectively, comprising transformer means having other than one-to-one ratios of transformation.

3. A converting system as specified in claim 1, the transformers having other than one-to-one ratios of transformation.

4. In a converting system, the combination with a single-phase circuit, of a polyphase circuit, connections from the mains of said single-phase circuit to certain mains of said polyphase circuit, a phase-converter, connections for inserting said phase-converter between said single-phase circuit and the remaining mains of said polyphase circuit, and means for inductively interlinking certain direct supply leads from said single-phase circuit to said polyphase circuit with certain leads from said single-phase circuit to said converter, respectively, the currents flowing in each pair of mutually interlinked leads being of relatively displaced phase and said inductive linkage being other than of a one-to-one ratio of transformation.

5. In a converting system, the combination with a single-phase circuit, of a polyphase circuit, connections from the mains of said single-phase circuit to certain mains of said polyphase circuit, a phase-converter, connections for inserting said phase-converter between said single-phase circuit and the remaining mains of said polyphase circuit, and means for inductively interlinking certain direct supply leads from said single-phase circuit to said polyphase circuit with certain leads from said single-phase circuit to said converter, respectively, the currents flowing in each pair of mutually interlinked leads being of opposite phase under balanced operating conditions, whereby said inductive interlinking means is normally inactive, said inductive interlinking means having other than a one-to-one ratio.

6. In a converting system, the combination with a single-phase circuit, of a polyphase circuit, connections from the mains of said single-phase circuit to two mains of said polyphase circuit, a phase-converter, connections for inserting said phase-converter between the mains of said single-phase circuit and the remaining mains of said polyphase circuit, and means for inductively interlinking the leads from said single-phase circuit to said converter with the leads from said single-phase circuit directly to said polyphase circuit, respectively, said inductive interlinking means having other than a one-to-one ratio.

7. In a converting system, the combination with a single-phase circuit, of a polyphase circuit, connections from the mains of said single-phase circuit to two mains of said polyphase circuit, a phase-converter, connections for inserting said phase-converter between the mains of said single-phase circuit and the remaining main of said polyphase circuit, and means for inductively interlinking the leads from said single-phase circuit to said converter, the currents flowing in mutually interlinked leads being of substantially opposite phase with respect to said interlinking means during balanced operation and said inductive interlinking means having other than a one-to-one ratio.

8. In a converting system, the combination with a single-phase circuit having a certain power factor, of a polyphase circuit having a different power factor, leads from the mains of said single-phase circuit to two

mains of said polyphase circuit, respectively, a phase-converter, connections for inserting said phase-converter between said single-phase mains and the remaining mains of said polyphase circuit, whereby energy may be transferred between said circuits, and transformer means interlinking leads from said single-phase circuit to said converter with leads to said polyphase circuit having a current phase-displacement of substantially 180° therefrom, whereby the unbalancing effects of the ohmic and inductive drops in said phase-converter may be compensated for, said transformer means having other than a one-to-one ratio.

9. In a converter system, the combination with a single-phase circuit having one power-factor, of a polyphase circuit having another power-factor, energy-transferring connections including a phase converter between said two circuits, said connections embodying leads wherein the currents have a relative phase-displacement of substantially 180°, and transformer means having other than a one-to-one ratio inductively interlinking said leads.

10. In a converter system, the combination with a single-phase circuit having one power-factor, of a polyphase circuit having another power-factor, energy-transferring connections including a phase-converter between said two circuits, said connections embodying leads wherein the currents are relatively displaced, and transformer means inductively interlinking said leads, said transformer means being so proportioned that the magnetic flux thereof is substantially zero when said polyphase circuit is balanced.

11. In a converter system, the combination with a single-phase circuit having one power-factor, of a polyphase circuit having another power-factor, energy-transferring connections including a phase-converter between said two circuits, said connections embodying leads wherein the currents are relatively displaced, and transformer means having other than a one-to-one ratio inductively interlinking said leads, said transformer means being so proportioned that the magnetic flux thereof is substantially zero when said polyphase circuit is balanced.

In testimony whereof I have hereunto subscribed my name this 10th day of Sept., 1917.

RUDOLF E. HELLMUND.