July 2, 1929. H. BENIOFF 1,719,356

PHASE MODIFIER

Filed Feb. 24, 1927 3 Sheets-Sheet 1

Fig. 1.

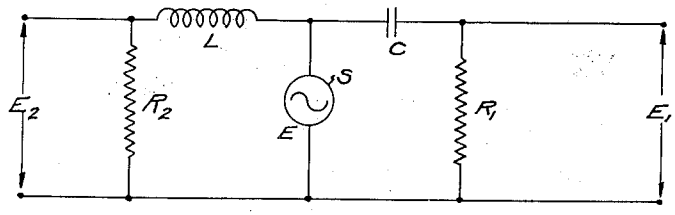


Fig. 2.

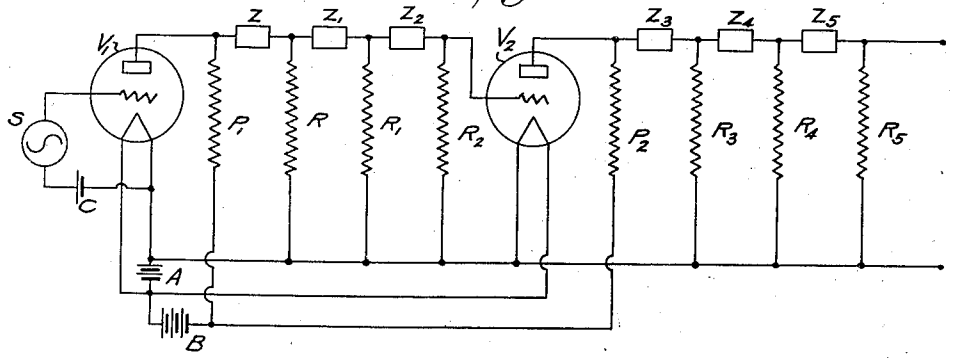
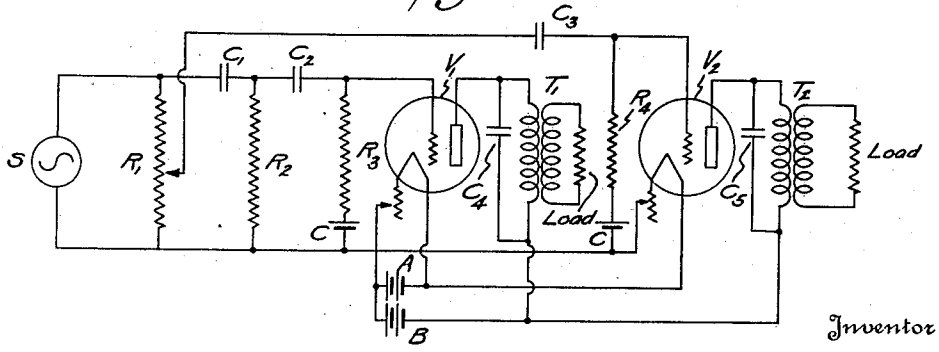


Fig. 3.



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PHASE MODIFIER

Filed Feb. 24, 1927 3 Sheets-Sheet 2

Fig. 4.

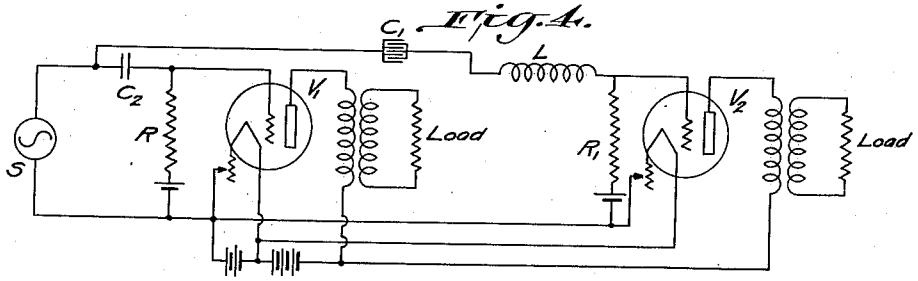


Fig. 5.

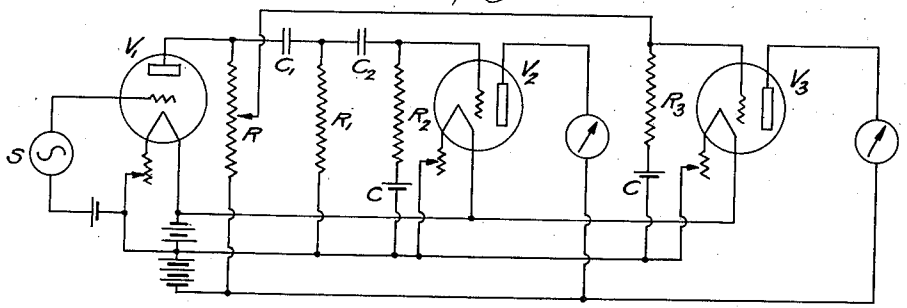


Fig. 6.

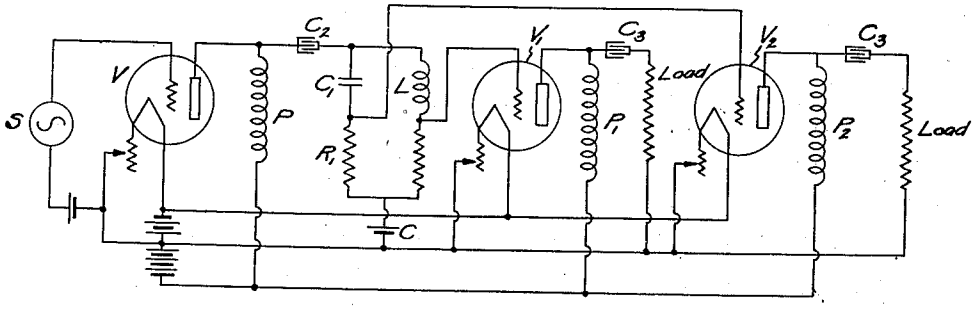
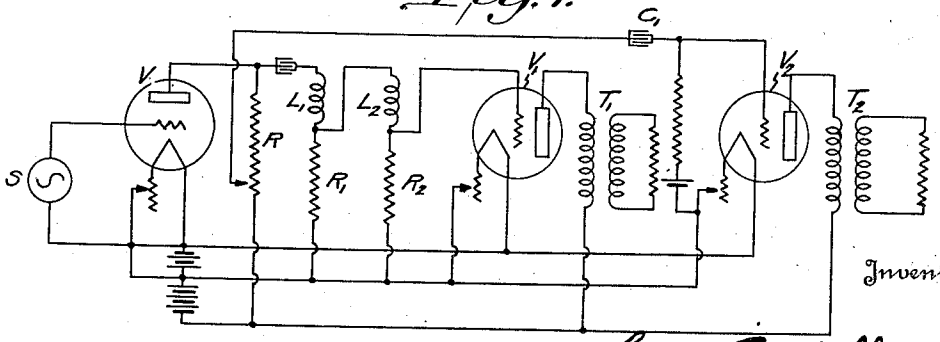


Fig. 7.



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July 2, 1929. H. BENIOFF 1,719,356

PHASE MODIFIER

Filed Feb. 24, 1927 3 Sheets-Sheet 3

Fig. 8.

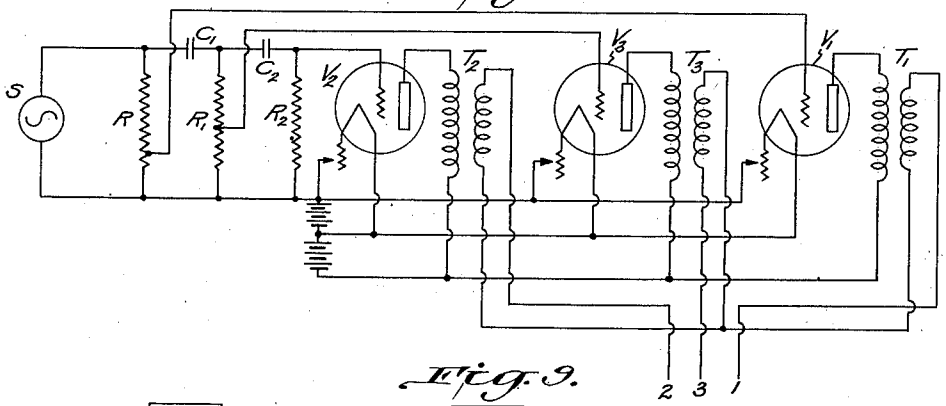


Fig. 9.

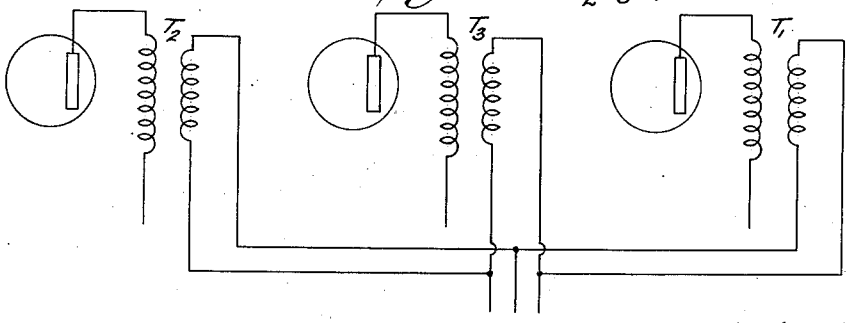
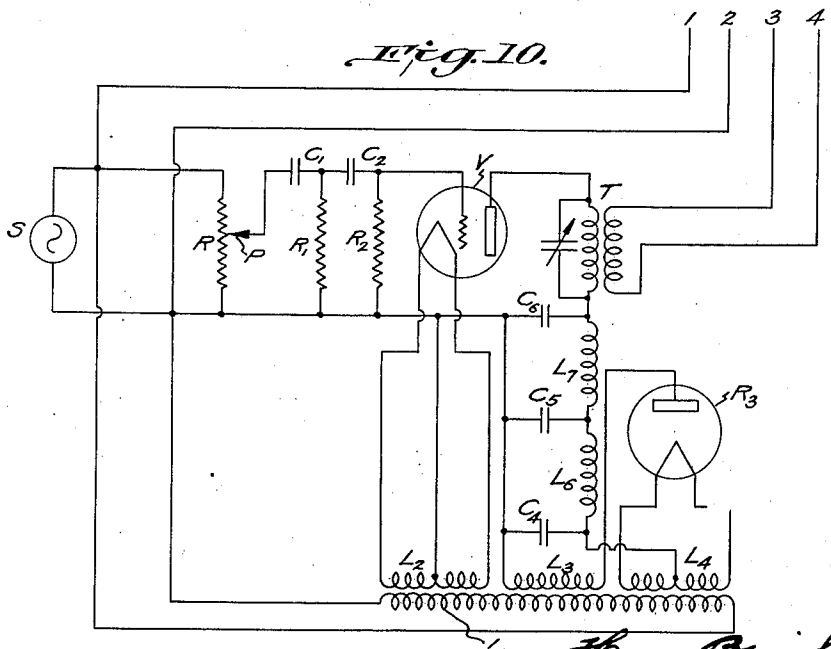


Fig. 10.



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UNITED STATES PATENT OFFICE.

HUGO BENIOFF, OF PASADENA, CALIFORNIA, ASSIGNOR TO CARNEGIE INSTITUTION OF WASHINGTON, OF WASHINGTON, DISTRICT OF COLUMBIA, A CORPORATION OF THE UNITED STATES.

PHASE MODIFIER.

Application filed February 24, 1927. Serial No. 170,715.

This invention relates to methods of and apparatus for modifying the phase of an alternating current and particularly to the production of multi-phase currents from a source of single phase current.

When an alternating current flows through a circuit including resistance and reactance, the current is of constant phase but the voltages across the resistance and reactance are not in phase. Although this phenomenon is well known, no simple and efficient method of obtaining split phases or multiple phases thereby has been previously devised since an attempt to withdraw power through a circuit shunted across a part of the basic circuit results in a change in the previously observed phase displacement. In accordance with the present invention, a load circuit may be supplied with current of a predetermined phase displacement through a relay of the voltage operated type, i. e. a vacuum tube. By a proper arrangement of the tube circuit, the operation of the relay is independent of the current flowing in the basic circuit; the phase of the voltage in the load circuit being dependent solely upon the voltage across those points in the basic circuit to which the input terminals of the tube are connected.

An object of the invention is to provide a method of and apparatus for obtaining from a source of single phase current other currents whose phase relationship is independent of the load in the circuit or circuits which they traverse. Another object relates to obtaining from a given single phase source, electric power with an electromotive force leading or lagging that of the given source by a predetermined angle. More specifically an object is to provide a method of and apparatus for obtaining from a source of low power, single phase current, two-phase currents of materially higher power.

These and other objects of the invention will be apparent from the following specification when taken with the accompanying drawings, in which:

Fig. 1 is a circuit diagram of alternating current circuits in which phase displacement occurs;

Fig. 2 is a diagram of a circuit for obtaining an electromotive force having a large angle of displacement;

Fig. 3 is a diagram of a circuit for obtaining a split phase current in which the voltage of the derived current leads the voltage of the source;

Fig. 4 is a diagram of a circuit for obtaining a derived current having a lagging voltage;

Fig. 5 is a diagram of a circuit for amplifying the voltage of the single phase source, and obtaining therefrom split phase currents, one being supplied from the amplified source and the other having a voltage leading the same by a predetermined angle;

Fig. 6 is a diagram of a circuit for obtaining split phase currents having voltages which lag and lead, respectively, that of the source;

Fig. 7 is a diagram of a circuit for obtaining split phase currents, one of which is supplied by the amplified source current and the other has a voltage lagging the first by a predetermined angle;

Figs. 8 and 9 are diagrams of circuits for obtaining three-phase currents connected in star and delta, respectively; and

Fig. 10 is a diagram illustrating an application of the invention in a power system.

In the circuit diagrams, the conventional symbols have been employed to designate the various types of reactances.

In Fig. 1, a source S of single phase current of votage E is shown as feeding into shunt circuit, one of which comprises a capacity C in series with a resistance R_1, while the other comprises an inductance L and series resistance R_2. The voltage E_1 across R_1 will lead the voltage E by an angle ϕ_1, and the voltage E_2 across R_2 will lag the source voltage E by an angle ϕ_2, the values of these angles being determined by the equations:

$$\tan \phi_1 = \frac{1}{\omega R_1 C}$$

$$\tan \phi_2 = \frac{\omega L}{R_2}$$

The voltages E_1 and E_2 will thus form a two-phase circuit in which the phases are displaced by the sum of the two phase angles. If this is equal to 90°, the circuits combine to produce a quarter-phase current. However, if an attempt is made to draw power from either the lagging or leading voltage, the

phase relations are disturbed and consequently this circuit cannot be employed as a source of polyphase power.

In accordance with this invention, the lagging or leading voltage is impressed upon the grid circuit of a vacuum tube, and proper precautions being taken, the grid circuit may be treated as though it were electrostatic; consequently power may be withdrawn from the plate circuit without appreciable alteration of the predetermined phase relationship of the basic circuit. With a suitable arrangement of transformers or other output devices, the voltage in the output circuit will be in phase with the grid voltage or will make a constant angle with it. It thus becomes possible to derive polyphase power from single phase power and to obtain it in any number of phases with any predetermined phase relationship.

Since the tangent of the phase angle in a given circuit is determined by the ratio of resistance to reactance, it follows that the maximum displacement of this angle is 90°. To approach this maximum value, however, the resistance R must approach zero and consequently the voltage of the displaced phase approaches zero. To obtain a high voltage displaced by angles of 90° or greater, a number of simple circuits may be cascaded as shown in Fig. 2. The source of single phase current S and grid bias battery C are arranged in series in the input circuit of a vacuum tube amplifier V_1, which amplifier is provided with the usual filament battery A and plate battery B. The direct current plate circuit is completed through the resistance P_1 and the tube functions in the ordinary manner to amplify the oscillatory currents impressed on the grid circuit. The phase displacement is provided by a series of cascaded circuits, each of which includes an impedance and a resistance in series, the succeeding circuits being shunted across the resistance element of the preceding units. As illustrated, the series impedance Z and resistance R are shunted across the plate circuit, a second series impedance Z_1 and resistance R_1 are shunted across the resistance R and a third unit comprising the impedance Z_2 and resistance R_2 is shunted across the resistance R_1 of the second unit. To preserve the phase relationship, the succeeding units in the cascade are of progressively higher impedance. As the voltage across succeeding resistances becomes progressively smaller, it may be necessary to insert an amplifier in the cascaded circuits to offset the progressive drop. The amplifier takes the form of a second vacuum tube V_2 which may be operated from the batteries which supply power to the first amplifier. The resistance R_2 constitutes the input circuit of the amplifier and a plate circuit is provided by a resistance or impedance P_2. Additional phase-displacing units may then be cascaded in shunt with the output circuit of the second amplifier. As illustrated, three units Z_3—R_3, Z_4—R_4, Z_5—R_5 are cascaded across the second amplifier. When the several impedances are capacitive the voltage across the terminal resistance R_5 leads the input voltage by a large angle, and when the several impedances are inductive the terminal voltage lags by a large angle.

The circuit illustrated in Fig. 3 is arranged to produce a two-phase power from a single phase source S. A resistance R_1 is shunted across the source and a cascaded phase changer C_1 R_2, C_2 R_3, is shunted across the resistance R_1. The resistance R_3 is arranged in series with a biasing battery C to form the input circuit of a vacuum tube amplifier V_1. The plate circuit of the amplifier includes a transformer T_1 for separating the direct and alternating current components of the space current and the load is connected across the secondary of the transformer. The voltage delivered to the load will lead the voltage of the source by a predetermined angle, and when quarter-phase current is desired the phase changer is adjusted to provide an angular displacement of 90°. When the source S delivers sufficient power the current for one of the quarter phases may be drawn directly from the source, the magnitude of voltage being regulated by tapping the supply from a suitable point along the resistance R_1. If, however, the source S is of comparatively low power, it is necessary to amplify the power before delivering it to the load circuit. This amplification may be obtained by inserting a vacuum tube amplifier V_2 between the tap on the resistance R_1 and the load circuit. The connection from the tap on R_1 includes a large blocking condenser C_3 and the tube input circuit consists of resistance R_4 and biasing battery C. The voltage impressed upon the amplifier V_2 is in phase with the voltage of the source S and the value of this voltage is regulated by the adjustable tap on the resistance R_1. The plate circuit of the tube V_2 includes a transformer T_2 having a secondary across which the load is connected. If desired, condensers C_4, C_5, may be shunted across the primaries of the transformers T_1, T_2, respectively. When the phase changer is designed to provide an angular displacement of 90°, the secondaries of the transformers deliver a quarter-phase current. The circuit as illustrated produces a quarter-phase current in which the voltage of the derived phase leads the amplified voltage of the source. By substituting inductances for the capacities C_1, C_2, the voltage of the derived phase will lag the voltage of the source.

The circuit shown in Fig. 4 will deliver two-phase current derived from the single phase source S. The input terminals of the tube V_1 are connected across the resistance R of the basic series circuit C_2 R and the input

terminals of the second tube V_2 are connected across the resistance R_1 of the basic series circuit L R_1. A capacity C_1 is introduced in the circuit L R_1 to insulate the grid circuit of the second tube. The voltages of the two-phase circuit are both displaced from the voltage of the source, one being a leading and the other a lagging voltage. When the constants are so chosen that the sum of the angular displacements is 90 electrical degrees quarter phase power is delivered to the load circuit.

When the source delivers a relatively low power, it may be amplified before it is passed to the basic phase displacing circuit. In the circuit of Fig. 5, the source S impresses its voltage upon the vacuum tube V and the amplified voltage drop across the plate resistance R is then used in place of the original source. One phase is displaced from the voltage across resistance R by means of the cascaded units C_1 R_1 and C_2 R_2, impressed upon the grid of tube V_1, and produces the current of leading voltage in the plate circuit P_1. The second phase is delivered by the tube V_2 which is energized by the voltage across resistance R_3. The voltage across R_3 is tapped from the resistance R by a tap which is adjustable to make the output voltage in plate circuit P_2 equal to the voltage in the phase derived through the tube V_1. A condenser C_4 is introduced in the lead to the tube V_2 to insulate the grid circuit. In this circuit, one phase has the voltage of the source and the voltage of the derived phase is a leading voltage.

With the circuit of Fig. 6, both voltages of the split phase current are displaced from that of the source S. As in the previous circuit, the voltage of S is amplified by tube V to provide a greater drop across the plate inductance P. Parallel phase changing circuits C_1 R_1 and L R_2 are shunted across the impedance P, through the insulating condenser C_2 and biasing battery C. The leading voltage across R_1 is applied to the grid of tube V_1 and the lagging voltage across R_2 is applied to tube V_2. The two load circuits are connected in parallel across their respective plate circuits P_1, P_2 with condensers C_3 introduced to separate out the direct current component of the plate currents. This circuit may be designed to deliver quarter phase power by adjusting the constants of the phase changing units to give angular displacements whose sum is 90 electrical degrees.

Fig. 7 illustrates a further circuit for obtaining phase displacements of the order of 90 electrical degrees or greater. In this circuit the voltage of the source S is amplified by tube V and a cascaded phase changer L_1 R_1, L_2 R_2, is shunted across the plate resistance R. The tube V_1 therefore delivers a lagging voltage to the secondary of the output transformer T_1. The voltage across the secondary of the transformer T_2 of the tube V_2 is in phase with the source since the voltage impressed upon the grid is obtained by a connection to an adjustable tap on the resistance R of the amplifier. The usual blocking condenser C_1 is provided to insulate the grid circuit of tube V_2.

The invention is not limited to the production of two phase power, and Figs. 8 and 9 show circuits adapted to deliver three phase power.

In the circuit of Fig. 8, a resistance R is shunted across the source S and two phase changing units C_1 R_1, C_2 R_2, are cascaded across the resistance. Vacuum tube V_1 is energized by the voltage existing in resistance R, tube V_2 is energized by the voltage across the terminal resistance R_2 and tube V_3 is energized with the voltage across the resistance R_1. As the voltage drop across the resistances becomes progressively smaller, the connections to resistances R and R_1 are adjustable for the purpose of equalizing the magnitudes of the voltages impressed upon the tubes. The secondaries of the output transformers T_1, T_2 and T_3 deliver three phase, star connected power to the load lines when the units C_1 R_1 and C_2 R_2 are each designed to produce a leading angle of 60 electrical degrees. The low sides of transformers T_1 and T_2 are connected to the high potential side of the transformer T_3. Phase 1 is the same as that of the source, phase 2 leads the source by 120 electrical degrees, and phase 3 leads the source by 240 electrical degrees, since the angular displacement produced by C_1 R_1 is 60 electrical degrees and the leads of the secondary of transformer T_3 are reversed.

To obtain delta connected three phase power, the secondaries of the transformers T_1, T_2 and T_3 of the circuit of Fig. 8 are connected in series as shown in Fig. 9. As in the star connection, the connections to the secondary delivery phase 3 are reversed.

By substituting inductances for the capacities employed in the phase changers of Fig. 8, the voltages of the two derived phases will lag the voltage of the source S. Three phase power may also be obtained by combining the source voltage with two voltages which lag or lead by 120 and 240 electrical degrees, respectively. To obtain displacements of 240 electrical degrees, however, a greater number of cascaded units will be required.

In the circuit diagram of Fig. 10, the source of power S may be an alternating current generator, a power line or the secondary winding of a transformer, and leads 1, 2 are connected at opposite sides of the source to provide a phase of the desired two-phase output power circuit. A phase changer comprises the cascaded units C_1 R_1 and C_2 R_2 which are connected across the source through the voltage regulating resistance R

and the adjustable tap P. The voltage drop across the terminal resistance R_2 is impressed upon the grid of the vacuum tube V and the resultant alternating current voltage in the plate circuit operates through the transformer T to supply the second phase of the output power circuit to the leads 3, 4. A tuning condenser is preferably included in shunt with the primary winding of the transformer T.

Although the filament and plate current for energizing the vacuum tube V may be supplied from batteries or other direct current source, these current supplies are preferably taken from the power source S. The primary L_1 of a power transformer T_1 is connected across the source S and current flowing therein induces current in the three secondary windings L_2, L_3, L_4. The secondary L_2 supplies current for heating the filament of tube V, and is provided with a center tap at which the plate and grid returns are connected. The secondary L_3 supplies current for the plate circuit through the rectifier tube R_3, which tube is of the hot cathode type and is energized by the secondary L_4. A filter of any suitable type, such as series inductances L^5, L^7 and shunt capacities C_4, C_5, and C_6, is employed to eliminate the alternating current components from the rectified plate current supply.

It will be understood that any desired angular displacement of one or more phases may be obtained by an appropriate design of the basic circuits, and that the phases produced may be combined in various relationships by the use of transformers or other appropriate devices. While the invention has been particularly described in connection with the production of quarter phase and three phase current, it is apparent that split phases of other relationships may be produced, and that power of more than three phases may be produced if desired.

I claim:

1. Apparatus for transforming single phase electric power to multiphase power having phases displaced by more than 90 electrical degrees, comprising a basic circuit across which the voltage of a single phase source may be impressed, said circuit including a plurality of phase displacing units each operative to produce an angular displacement of substantially less than 90 electrical degrees, displacement circuits connected across separate pairs of points in said basic circuit at which voltages displaced by not less than 90 electrical degrees occur, and electrostatic relays energized by the respective displacement circuits, the output circuits being associated with each other to deliver multiphase power to a load.

2. Apparatus as set forth in claim 1, wherein each of said units comprises series reactance and resistance, and certain of said units are cascaded by connecting each unit in turn across the resistance of the preceding unit.

3. Apparatus as set forth in claim 1, wherein two phase displacement circuits are employed and are connected to pairs of points in the basic circuit at which the phase displacement is 90 electrical degrees, whereby quarter phase power is delivered to the load.

4. Apparatus as set forth in claim 1, wherein one relay is energized by the source voltage and the input circuit of a second relay is connected across a part of the basic circuit at which the voltage is displaced from that of the source by 90 electrical degrees.

In testimony whereof, I affix my signature.

HUGO BENIOFF.