Aug. 18, 1942. F. A. COWAN 2,293,595

PHASE CONTROL SYSTEM

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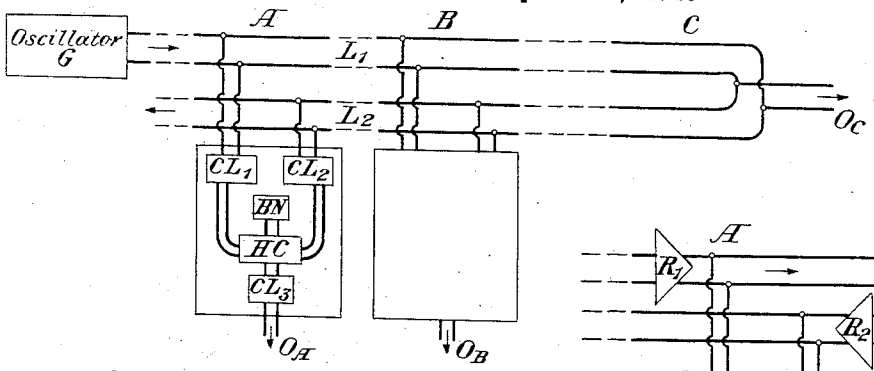


Fig. 1

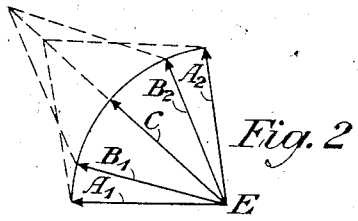


Fig. 2

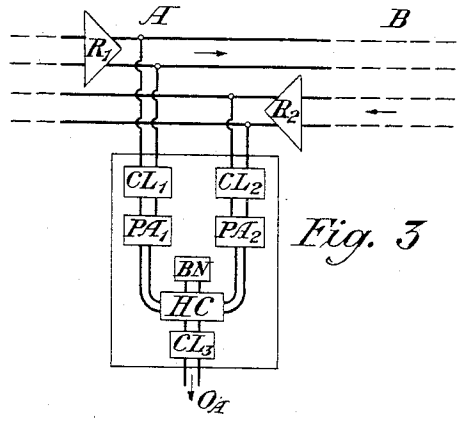


Fig. 3

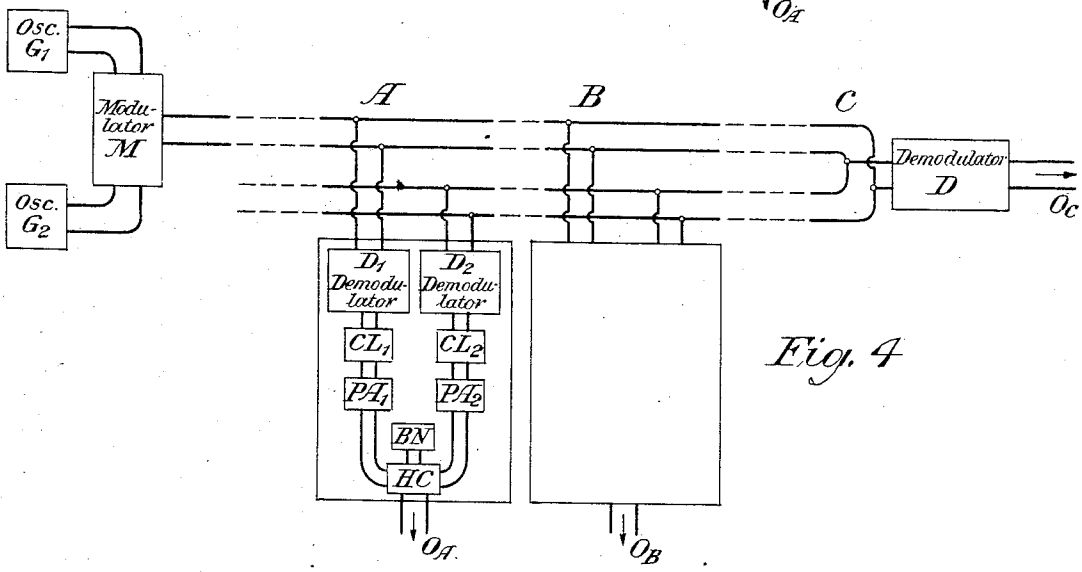


Fig. 4

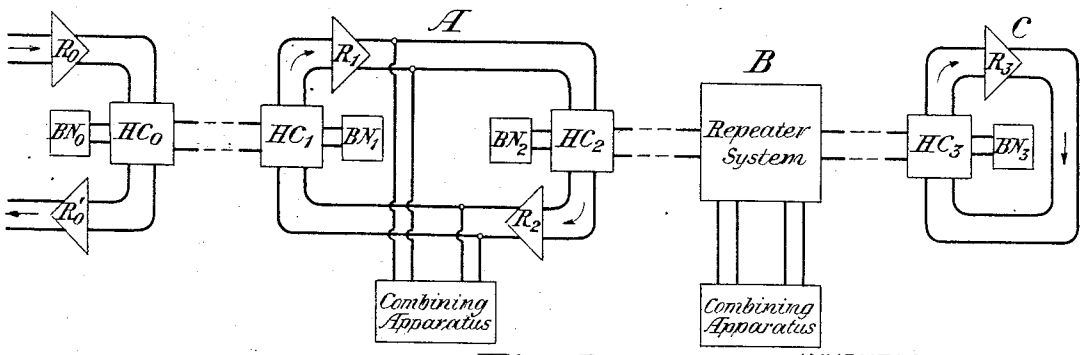


Fig. 5

INVENTOR
F. A. Cowan
BY
William P. Ballard
ATTORNEY

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PHASE CONTROL SYSTEM

Frank Augustus Cowan, New York, N. Y., assignor to American Telephone and Telegraph Company, a corporation of New York

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12 Claims. (Cl. 178—44)

This invention relates to electrical transmission systems and, more particularly, to systems arranged to provide alternating current or voltage of the same phase at a plurality of points.

When current of a particular frequency is transmitted over a line, there will inevitably be a shift in the phase of the current corresponding to a phase delay. This will occur even when the line is perfect. This phase shift will generally change with temperature and weather changes and with variations in battery supply and equipment characteristics. Such conditions are in general uncontrollable, especially over a long line.

It is therefore one of the objects of this invention to provide a system in which the phase relationships are identical at a plurality of points which may be widely distant from each other.

The method of this invention takes advantage of the tendency of two lines which are of substantially identical structure and are subjected to the same conditions to undergo the same normal phase shift but also substantially the same variations in the phase shift. The method may be applied to a line, such as a telephone line, over which current of a predetermined frequency is transmitted, the current passing points A and B and other points along the route and reaching point C where the line or circuit is looped back over the same route through points B and A. If the outgoing and return circuits are identical and subject to the same conditions of temperature and weather and other effects, the current will undergo the same shift in phase in traveling from A (or B) to C as it does in returning from C to A (or B). Thus the phase of the current at points A and B along the outgoing circuit will lead the current at point C by the same amount as the phase of the current in the return circuit at the same point will lag behind the current at C. It happens, however, that the vector sum of the currents of the outgoing and return circuits at points A and B and at every other point along the route may be caused to yield a resultant which is in phase with, or in phase opposition to, the current at point C. The condition of phase opposition can be readily detected and corrected at once. Consequently, the scheme suggested will yield currents at a plurality of diversified points which are of the same phase.

This invention will be better understood from the detailed description hereinafter following when read in connection with the accompanying drawing in which Figure 1 illustrates one embodiment of the invention suitable for providing currents of equal phase and amplitude at a plurality of different points, Fig. 2 is a vector diagram illustrating the principles involved in the invention, Fig. 3 is a modification of the arrangement shown in Fig. 1, Fig. 4 shows still another modification of the invention and Fig. 5 shows the invention applied to a two-wire circuit.

Referring to Fig. 1 of the drawing, there is shown an oscillator G connected to a line L_1 which extends through points A and B to point C, the line L_1 being connected at point C to an identical or substantially identical line L_2 and returned over the same route through points B and A. Assume that the alternating current supplied by oscillator G has the same phase at points A, B, and C. Then if the temperature or weather or other conditions along the route are such that the phase of the current at point A of line L_1 leads the current in line L_1 at B and that at B leads the current at C, in the return line L_2 the phase of the current at B will lag behind that at point C, and likewise the phase at point A of line L_2 will be further retarded. Thus the currents in either line will be out of phase with each other. But if the currents in the two lines at point A are equal or are made equal in magnitude and combined vectorially, their resultant will be in phase with the current at point C. Similarly if the currents of both lines at point B are added vectorially, their resultant will also be in phase with the current at point C. Thus the phases of the resultants at points A and B will be the same as the phase of the current at C. Any form of circuit for vectorially combining the currents at point A (or at point B or at any other point along the route) may be used in the practice of this invention, one such circuit being shown and described in the A. Bailey et al. Patent No. 1,780,962, issued Nov. 11, 1930.

If the currents to be combined are to have the same amplitude as well as the same phase at the various points such as A, then the combining apparatus at point A may take the form shown in Fig. 1. Two current limiters CL_1 and CL_2 of well known type are connected respectively to lines L_1 and L_2. These limiters may be, for example, overloaded amplifiers of the well known vacuum tube type, the grid circuits of which are supplied with the currents obtained from lines L_1 and L_2 respectively and the plate circuits receive the amplified currents which may

not exceed a predetermined value. The current outputs of the two limiters CL_1 and CL_2 are thus made equal in value though their phases differ by equal but opposite angles from the phase of the current at point C. These equal currents may be fed to a hybrid coil network of the type disclosed, for example, in the A. Bailey et al. patent already referred to and hence are added together vectorially. A balancing network BN of well-known type is connected to the hybrid coil network, this balancing network having an impedance substantially equal to the input impedance of the current limiter CL_3 to which the combined currents are transmitted. The limiter CL_3 is similar to the limiters CL_1 and CL_3 and hence transmits a current of predetermined magnitude to the circuit O_A. The current fed to circuit O_A will not only have a predetermined magnitude, but its phase will always equal the phase of the current at point C. An identical current will also be obtained from circuit O_B. A similar current limiter may also be employed at point C if so desired, especially where large level variations are encountered at that point.

Although a hybrid coil network system has been shown for illustrative purposes for combining the component currents, such an arrangement is by no means essential. The networks HC and HN may be omitted, if desired, in which case the limiter CL_3 may be supplied directly with the outputs of the limiters CL_1 and CL_2.

Fig. 2 illustrates the phases of the currents at different points along the lines L_1 and L_2. Here the vectors A_1 and B_1 represent the phases of the currents at points A and B of line L_1 and vectors A_2 and B_2 the phases of the currents at these same points, respectively, in line L_2. The phase of the current at point C where the lines L_1 and L_2 meet is represented by the vector C in Fig. 2. All of these vectors are of the same magnitude, this condition having been brought about by the current limiters of Fig. 1 which supply currents of equal amplitude to the combining network HC.

From Fig. 2 is will be observed that vector A_1 leads vector B_1 by an angle which is equal to the angle by which vector A_2 lags behind vector B_2. It will also be observed that the vectorial angles A_1 EC and A_2 EC are equal to each other as are also the vectorial angles B_1 EC and B_2 EC.

According to this invention, the vector addition of the vectors A_1 and A_2 yields a third vector which has the same direction as vector C. Likewise, the vector addition of vectors B_1 and B_2 yields another vector which also has the same direction as vector C. In other words, the addition of the currents of the two lines L_1 and L_2 at any point such as A of Fig. 1 will produce a current which is of the same phase as the current resulting from the addition of the currents of lines L_1 and L_2 at any other point such as B and the resultant currents at the various points will also be in phase with the current at point C.

The resultants of the various pairs of component currents shown in Fig. 2, while of the same phase, have somewhat different magnitudes as will be apparent from the drawing. However, the current magnitudes at the various points may be equalized by a limiter such as CL_3 of Fig. 1. This limiter may be adjusted to transmit a current which will have an amplitude either equal to that obtained at point C, or greater or less than the current at point C, as may be desired. Whatever the resultant current it will often be desired, however, to have these currents in the various output circuits O_A, O_B, etc. of the same phase. Such currents will be obtained with the arrangement of this invention.

The arrangement of Fig. 1 may be modified in the manner illustrated in Fig. 3. If point A is a repeater point, repeaters R_1 and R_2 may be added to lines L_1 and L_2 respectively. If the repeaters R_1 and R_2 are overloaded repeaters which act as current limiters, they will perform the amplitude equalizing functions of the limiters CL_1 and CL_2 respectively and therefore the latter devices may be dispensed with.

The currents of equalized amplitudes may be impressed upon the respective phase adjusting networks PA_1 and PA_2 of Fig. 3, these phase adjusting networks being used to bring the phases of the component currents to be combined at any point such as A to predetermined phase relationships. Thus, the phases of the currents at point A may be adjusted at some predetermined temperature, weather or other conditions to have the phase angles of vectors A_1 and A_2 of Fig. 2, or any other phase angles with respect to the phase of the current at point C. As in Fig. 1, the currents of lines L_1 and L_2—which lead and lag behind the current at point C by the same amount—will be added vectorially in the network HC and the resultant will then be transmitted through the limiter CL_3 to the output circuit OA. A similar phase adjusting arrangement may be employed at each selected point along the route. It is one of the features of this invention to have a system such that, after the phases of the currents tapped from the lines L_1 and L_2 at each of various points, such as A, along the route are brought to equal and opposite angles with respect to that at C, the resultant currents appearing in circuits O_A, O_B, etc., will have phases equal to that at C at all times thereafter. These phase adjusting networks may be used in the practice of this invention even when repeaters such as R_1 and R_2 are not embodied in the system.

It will be noted that the phase of the current at the point C at the distant end of line L_1 of Fig. 1, or in any modification thereof, will differ from that of the reference source G by the phase shift over the intermediate line L_1. The difference in phase between source G and point C is subject to all the variations in phase exhibited by line L_1. The resultant currents, i. e., the vector sums of the two currents in lines L_1 and L_2, at the intermediate points A, B, etc., will also vary in phase with respect to source G, but all will vary alike and the resultant currents at these points will have the same phase as the current at point C.

In Fig. 2, the vectors A_1 and A_2 at point A, for example, are shown to be less than 90° apart. In practice, it will be found that the directions of both vectors will change with different conditions of temperature or weather or other factors, although both vectors will continue to form equal but opposite angles with vector C. As the angle between the vectors A_1 and A_2 exceeds 120°, their resultant, while in the same direction as vector C, will nevertheless have a magnitude which is less than that of vector C. Such a condition can be overcome whenever desired by proper initial adjustments of the phase adjusting networks PA_1 and PA_2 of Fig. 3. Thus by properly adjusting networks PA_1 and PA_2 the phase angle between the vectors A_1 and A_2 can be kept below a 120° value under the ordinary conditions of operation.

However, if it is unnecessary that the magnitudes of the resultant currents exceed the magnitude of the current at C, the phase shift between vectors A_1 and A_2 may be permitted to reach any value up to 180° without reversing the direction of the resultant currents. But an angular displacement in excess of 180° will effectuate a reversal of the currents in circuits O_A, O_B, etc. and such a condition can also be overcome whenever desired by the initial setting of the phase adjusting networks PA_1 and PA_2 so as to maintain the angular displacement less than 180°.

If current limiters such as CL_1, CL_2 and CL_3 are employed, they will raise the amplitudes of the various currents by large amounts with the result that all component currents, whatever their phase angle displacement, will yield large resultant currents which will have substantially equal magnitudes.

As is well known in the art a phase adjusting network may comprise, for example, a coil and condenser in parallel with each other, either or both of which may be adjustable. By suitable use of any such networks, one may limit the change in phase in the output currents of such networks to some predetermined angle, such as 90° under certain conditions. By so limiting the angular displacement of the two component currents at a point such as A, for example, the resultant currents will then always have the same phase angle as the current at point C and their magnitudes will at all times exceed a predetermined value.

The absolute value of the current in any one of the output circuits such as O_A, i. e., the vector sum of the outgoing and return currents in lines L_1 and L_2 respectively, will vary as the cosine of the angle corresponding to the electrical length of either of the two lines extending between the intermediate point A and the distant terminal C. If under average conditions the two current components are brought into phase by inserting the networks PA_1 and PA_2 and adjusting them so as to introduce equal and opposite phase-rotational effects of suitable displacements in the currents of the two branches of the combining circuits before they are impressed upon the network AC, then a variation in the phase of the currents of ±90° may be tolerated before the vector sum vanishes. The vector sum will indeed become negative if the phase variation exceeds 90°.

However, this is not a serious limitation upon this invention. 60-cycle phase service may be readily given with the circuits already described and these circuits, if of the cable type, may be more than 500 miles long and if of the open-wire type, the circuits may be twice that long.

Fig. 4 illustrates a system for extending the circuit lengths considerably. Here two sources of current G_1 and G_2 are used, one of which is of a high frequency and the other of a relatively low frequency. The low frequency current, i. e., the current of source G_2, which may be a 60-cycle current, for example, is modulated by modulator M upon the high frequency current of a frequency, for example, of 1000 cycles, the modulation process producing both side bands of the carrier as well as the carrier current. These currents are demodulated at the various points A, B and C along the route by demodulators D_1 and D_2, for example, at point A and by demodulator D at point C. The demodulated currents may be of a frequency which is equal to that of source G_2. These currents may then be added together vectorially as already explained in connection with Figs. 1 and 3.

The generator G_1 is preferably one which supplies current of a frequency which can be efficiently transmitted over the telephone lines L_1 and L_2. If other types of lines are employed, then the frequency of generator G_1 may be changed to supply a current which can easily be transmitted over such lines. By using the system of Fig. 4, the 60-cycle phase service may be given over cable circuits upwards of 10,000 miles in length without exceeding the ±90° phase-shift limit already referred to.

Figs. 1, 3 and 4 illustrate the invention applied to systems having distinctly different circuits for the two directions over which the generated currents are to be transmitted. If desired, a single two-wire line of the type shown in Fig. 5 may be used for the two directions of transmission and such a scheme will have an advantage over the others in that the phase variations in the two directions of transmission will be more closely identical.

In Fig. 5 the source of current is transmitted through repeater R_0 and through the hybrid coil network HC_0 and the returned current is received through the repeater R'_0. At point A, the currents received from the westerly line are transmitted through the hybrid network HC_1, then through repeater R_1 and hybrid network HC_2 to the point B. Current returned from point B is received by the network HC_2 and passed through repeater R_2 to the network HC_1 where it is passed back over the line in the westerly direction. The repeater system at point A is thus of the so-called two-wire two-way type.

At the point A the outputs of the repeaters R_1 and R_2 may, if desired, be added together vectorially by any of the combining circuits already referred to in Figs. 1 and 3 and therefore need not be further described. A similar repeater system and combining apparatus may be used at point B.

At point C, however, the incoming currents are transmitted through hybrid network HC_3 and repeater R_3 and are then returned to the same hybrid network HC_3 in a well-known manner. These currents are transmitted back through the repeater systems at points B and A to the repeater R'_0. In regard to the circuit of Fig. 5, it will be apparent that the circuits of the combining apparatus may be connected across the input circuits of the repeaters R_1 and R_2, if so desired, all of which is within the scope of this invention.

The generators of current such as G, G_1, G_2, etc. may be any well known types of generators of alternating current, preferably controlled by tuning forks or piezo-electric crystals or the like to maintain a highly constant frequency. Although the phases of the resultant currents at each point along the route are the same as the reference point C, there will nevertheless be a small frequency change resulting from the use of the circuits of this invention. This change—which is due primarily to the variations in the line on account of temperature, weather or other changes—is, however, extremely small and is of no practical effect. This invention hence stabilizes the relative phases of the resultant currents without appreciably affecting the absolute frequency of the current transmitted.

The methods and apparatus employed in this

invention are a distinct improvement over prior art systems in that no use is made of mechanically rotating or moving parts. In practicing the invention there is no conversion of mechanical displacements into electrical effects or vice versa. This is believed to be one of the important features of this invention.

While this invention has been shown and described in certain particular arrangements merely for the purpose of illustration, it will be understood that the general principles of this invention may be applied to other and widely varied arrangements without departing from the spirit of the invention and the scope of the appended claims.

What is claimed is:

1. The method of supplying alternating current of a common phase to a plurality of points which consists in transmitting said current along a circuit beyond said points, returning said current over a similar circuit through said points and combining the currents in the two circuits at each of said points to yield currents of common phase.

2. The combination of a source of alternating current, a first circuit connecting said source with a distant point, a second circuit connected to the first circuit at said distant point and paralleling the first circuit, and means for combining currents in the first and second circuits which have equal but opposite phase relations with respect to the current at the distant point to produce current of a phase equal to the phase of the current at said distant point.

3. The method of supplying alternating current of a common phase to a plurality of points which consists in transmitting said current along two circuits one of which extends beyond said points and the other returns said current through said points, equalizing the amplitudes of the currents in the two circuits at each point, and adding the equalized currents vectorially at each point.

4. The combination of a circuit carrying a single alternating current, said circuit being looped back on itself so that two currents may be tapped from its two branches at any point, said two currents having equal and opposite phase displacements with respect to a particular current, two circuits for separately equalizing the amplitudes of the two currents, and means interconnecting said two circuits for adding the two equalized currents therein vectorially.

5. The combination of a circuit carrying a single alternating current, said circuit being looped back on itself so that two currents may be tapped from its two branches at any point, said two currents having variable phase angles with respect to each other which vary equally with respect to the phase of a standard current, two current limiters for equalizing the two respective currents and a network for adding the two currents vectorially.

6. A circuit for combining two currents of different phases comprising two current limiters for equalizing the amplitudes of the two currents, two phase adjusting networks connected respectively to the current limiters for adjusting the relative phases of the two currents, and a network for vectorially adding the currents emanating from the phase adjusting networks.

7. The method of obtaining cophasal currents at a plurality of points which consists in transmitting alternating current over a circuit passing through said points and extending to the most distant of said points, returning the current over an identical circuit through the same points, tapping the two circuits at each point and equalizing the amplitudes of the currents so tapped, and adding the equalized currents vectorially.

8. The method of obtaining current of a predetermined phase which consists in producing two currents of equal amplitude which have equal but opposite phase angles which vary equally with respect to a standard current of predetermined phase, and adding the two currents vectorially.

9. The method of supplying current of predetermined phase to a remote point which consists in generating an alternating current, deriving therefrom two currents of phases which are equal but opposite to that of the predetermined phase, equalizing the amplitudes of said two currents, and combining said two currents vectorially.

10. The combination of two sources of alternating current, two equal circuits paralleling each other over which said currents may be transmitted in tandem, means for superimposing one of the currents upon the other and transmitting said currents so superimposed over said circuits, means for deriving the superimposed current from both circuits, means for equalizing the amplitudes of the derived currents, and means for combining said equalized currents.

11. The method of supplying current of predetermined phase to a plurality of distant points which consists of transmitting alternating current through said points, returning said current through the same points, and adding vectorially the transmitted and returned currents at each of said points.

12. Apparatus for supplying current of predetermined phase to a plurality of remote points comprising a circuit extending through said points over which alternating current is transmitted and returned, means for deriving two currents at each point conjugate to one another in phase with respect to the predetermined phase, and means for adding the two conjugate currents at each point.

FRANK AUGUSTUS COWAN.