

Dec. 24, 1940.

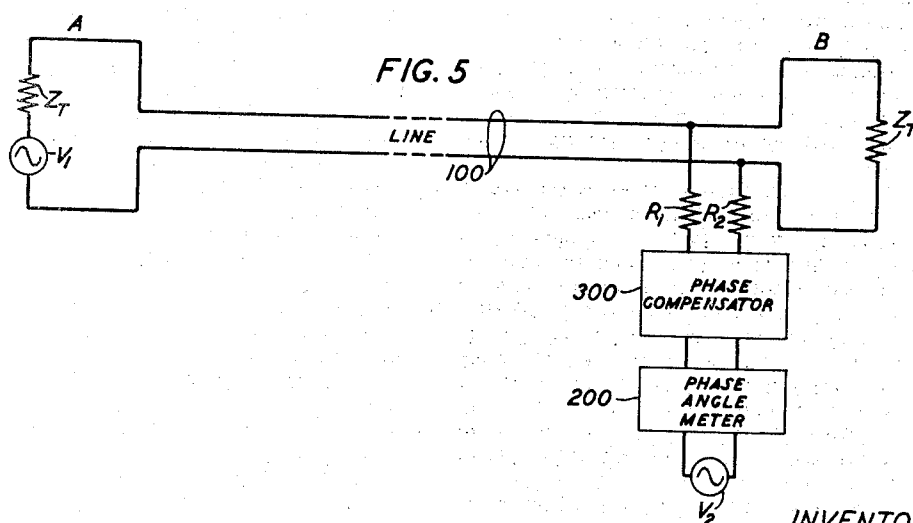
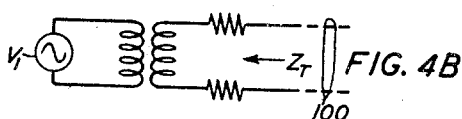
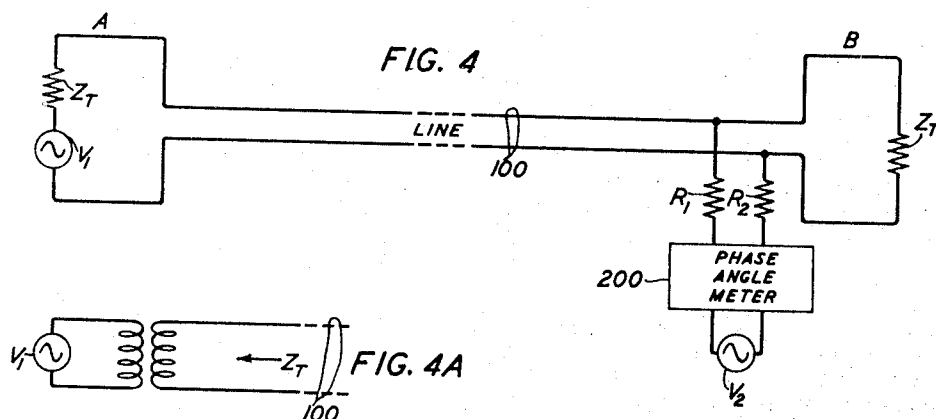
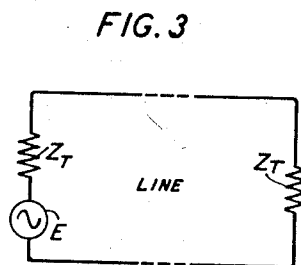
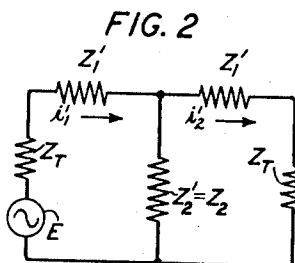
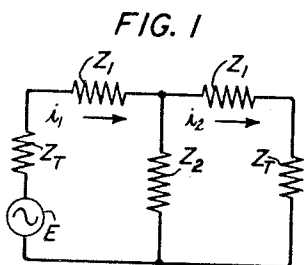
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2,225,653

COMPENSATION FOR VARIATIONS IN PHASE CHANGE

Original Filed Feb. 21, 1939

2 Sheets-Sheet 1



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FIG. 6

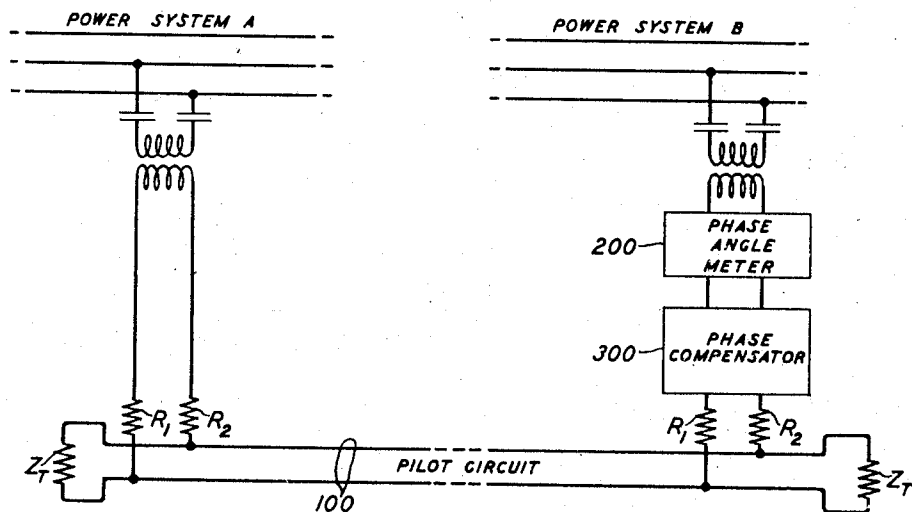
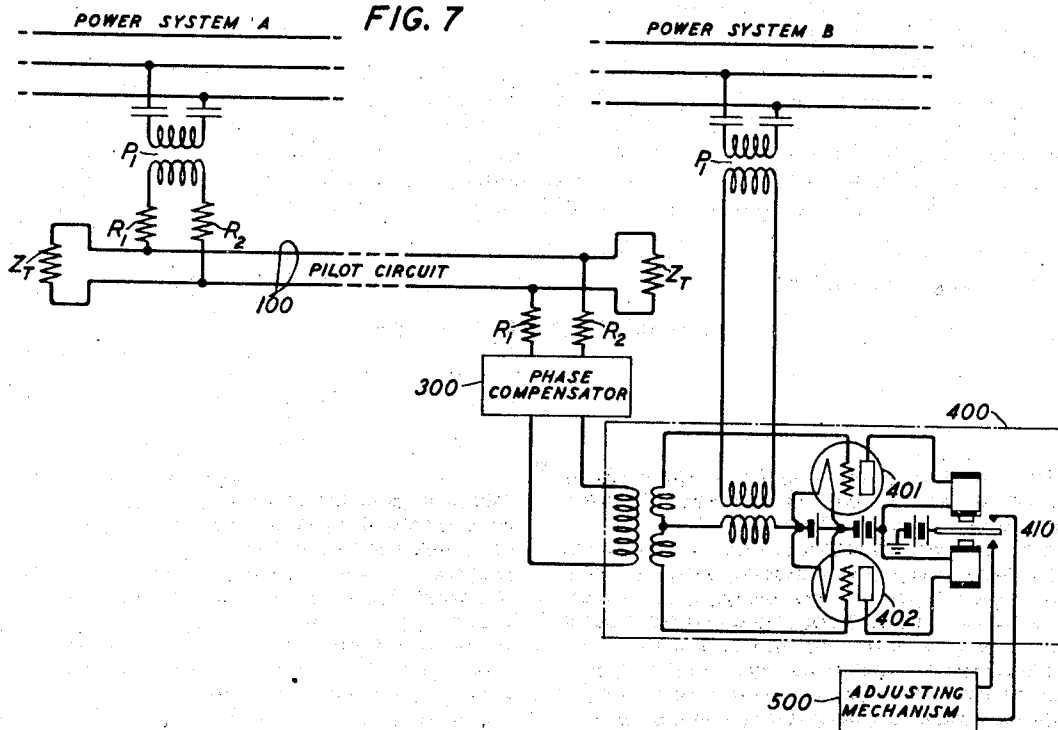


FIG. 7



CONNECTION
TO LOCAL CONTROL
APPARATUS

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2,225,653

COMPENSATION FOR VARIATIONS IN PHASE
CHANGE

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Original application February 21, 1939, Serial No.
257,674. Divided and this application Decem-
ber 20, 1939, Serial No. 310,129

6 Claims. (Cl. 172-246)

This is a division of an original application
Serial No. 257,674, filed February 21, 1939, for
Compensation for variations in phase change.

This invention relates to a method and means
for substantially reducing variations in the phase
characteristic of a transmission circuit particu-
larly at any one frequency and is applicable more
especially to a cable circuit.

An object of this invention is to provide a new
and improved method and means for substan-
tially reducing variations in the phase character-
istics of a cable circuit particularly at any one
frequency due to varying weather conditions or
other causes.

Another object is to provide a method and
means for improving transmission characteristics
of cable circuits.

A further object is to provide a pilot circuit, in
which variations in phase change are substan-
tially eliminated, for use in measuring the phase
relationship of the current at different points in
an electrical system.

This is accomplished primarily by terminating
each end of the circuit in a specific impedance as
described below. The method is applicable to
those circuits for which the shunt impedance of
the equivalent T-network remains very nearly a
pure reactance for various conditions to which a
cable may be subjected, such, for example, as
temperature changes; in other words, for cases
in which the effect of leakage is very small or
negligible. This is true for transmission of cur-
rents of frequencies up to the order of several
thousand cycles over cable circuits of some
length.

A description of an embodiment chosen for
illustrating this invention, in which reference is
made to the accompanying drawings, follows:

Fig. 1 is an equivalent T-network of a cable
circuit;

Fig. 2 is an equivalent T-network of the cable
circuit of Fig. 1 showing the impedance changed
due to varying weather conditions or the like;

Fig. 3 shows an application of terminating im-
pedances according to the principles of this in-
vention for compensating for variation in phase
characteristic of a circuit when an alternating
current is transmitted thereover;

Fig. 4 shows an application of this invention
for measuring by means of a pilot line the phase
differences between voltages at two points;

Figs. 4A and 4B show different arrangements
for connecting an alternating voltage source to
the pilot line arrangement of Fig. 4;

Fig. 5 shows an application of this invention

for measuring by means of a pilot line the phase
differences between voltages at two points in
which compensation is introduced for the change
in phase introduced by the pilot line itself;

Fig. 6 shows an application of this invention
for measuring by means of a pilot circuit the
phase angle differences between different points
of a power system or systems; and

Fig. 7 shows an application of this invention to
power transmission for automatically maintain-
ing the current at different points of the system
or systems in phase.

The underlying principles of this invention are
first described by referring to the equivalent T-
network included in Figs. 1 and 2; while certain
applications are described in connection with
subsequent figures.

Referring to Figs. 1 and 2, the former shows a
cable circuit reduced to its equivalent T-network
under given conditions, and the latter under
somewhat different conditions when the imped-
ance is changed from that shown in the former.
The network is assumed to be connected to a
generator E of impedance Z_T and terminated in
an impedance also of value Z_T . If the imped-
ances of the equivalent T-network of Fig. 1
change due to varying weather or other condi-
tions, a new network as indicated in Fig. 2 re-
sults, in which the impedances Z_1 and Z_2 may be
considered to have new values Z_1' and Z_2' . If the
leakage can be neglected the value of the shunt
impedance Z_2' will be equal to that of the origi-
nal network or Z_2 .

The ratio between the currents i_2 and i_2' de-
termine the variation in phase change. These
currents may be expressed as follows:

$$i_2 = \frac{EZ_2}{2(Z_1 + Z_T)Z_2 + (Z_1 + Z_T)^2} \quad (1)$$

$$i_2' = \frac{EZ_2'}{2(Z_1' + Z_T)Z_2' + (Z_1' + Z_T)^2} \quad (2)$$

and their ratio is

$$i_2/i_2' = \frac{2(Z_1' + Z_T)Z_2' + (Z_1' + Z_T)^2}{2(Z_1 + Z_T)Z_2 + (Z_1 + Z_T)^2} \times \frac{Z_2}{Z_2'} \quad (3)$$

or if $Z_2' = Z_2$

$$i_2/i_2' = \frac{2(Z_1' + Z_T)Z_2 + (Z_1' + Z_T)^2}{2(Z_1 + Z_T)Z_2 + (Z_1 + Z_T)^2} \quad (4)$$

If the value of Z_T is now made very large the
impedances Z_1 and Z_1' (which will be only
slightly different from Z_1) may be neglected and
the right-hand side of Equation 4 reduces to
unity indicating that the phase change between
the two currents is zero.

It is obvious from Equation 4 that the value of Z_T may be any value large in comparison with Z_1 and may be either a resistance or a reactance. However, it must not be so great that the attenuation becomes excessive. In order to determine the best value for the impedance Z_T the expression for the attenuation, that is, the relation between the currents i_1 and i_2 may be written:

$$\frac{i_2}{i_1} = \frac{Z_2}{Z_1 + Z_2 + Z_T} \quad (5)$$

which neglecting Z_1 reduces to

$$\frac{i_2}{i_1} = \frac{Z_2}{Z_2 + Z_T} \quad (6)$$

From this expression and the maximum value of attenuation, which may be allowed, the value for Z_T may be determined.

The results which may be obtained with this method for reducing the variations in phase change of the circuit will, of course, depend upon the relative values of Z_1 and Z_T . If the attenuation is permitted to be large, the value of Z_T can be made very large and the variation in the phase change can be eliminated for all practical purposes.

This method is applied in the following example to an actual cable circuit at 60 cycles taking a non-loaded 19-gauge cable circuit 10 miles in length. The fundamental constants for such a circuit at 68° F. are as follows:

$R=85$ ohms per mile
 $L=.00106$ henry per mile
 $C=.066$ mfd. per mile
 $G=.1$ micromho per mile

Considering a temperature change from 68° F. to 32° F., which is roughly the yearly temperature variation for underground cable, the values for the fundamental constants at 32° F. are as follows:

$R=78.2$ ohms per mile
 $L=.00106$ henry per mile
 $C=.0654$ mfd. per mile
 $G=.05$ micromho per mile

It is assumed that the leakage G is equal to 0.1 micromho per mile and that it changes 50 per cent over the temperature range from 68° F. to 32° F.

Employing these fundamental constants, the equivalent T-networks for a 10-mile circuit work out to have the following impedance values:

68° F.	32° F.
$Z_1 = 426 - j3.6$	$Z_1' = 390 - j2.7$
$Z_2 = 402 \sqrt{91^\circ.28}$	$Z_2' = 4059 \sqrt{91^\circ.22}$

If an attenuation of 20 decibels is permitted the maximum value of resistance or reactance which may be employed for Z_T is from Equation 5 about 40,000 ohms.

Substituting the above values for Z_1 , Z_1' , Z_2 , Z_2' and Z_T into Equation 3 we find that the variation in phase change will be as follows:

Z_T	Variation in phase change
Ohms	Degrees
40,000	.18
+j40,000	.20
-j40,000	.14

This compares with a total variation in phase change of about 1.0 degree which would obtain if the circuit were terminated in characteristic impedance.

The leakage in such a circuit may, however, be considerably different from 0.1 micromho per mile at 68° F. Furthermore, the change in leakage over the temperature range assumed may be considerably less than 50 per cent. If either the leakage is less than that assumed or the change in leakage is less than 50 per cent, the variation in the phase change will be less than the computed values given above.

The figures given are merely for illustrative purposes. By increasing the value of Z_T the variation in phase change can be still further reduced. This will, however, increase the overall attenuation of the circuit.

Fig. 3 shows an application of terminating impedances to a transmission line according to the principles of this invention for compensating for variations in the phase characteristics of a circuit when an alternating current is transmitted. The values of the impedances Z_T at each end of the line are so determined that when the voltage of an alternating current of a given frequency generated by source E is impressed upon the line, the variation in phase change caused by the transmission line is neutralized or reduced. Such a compensated line may be used by itself or as a pilot circuit in conjunction with other circuits or systems, examples of which are subsequently described herein.

The method and means described above of providing a circuit of substantially constant phase characteristic may be utilized in various ways, a number of illustrative applications of this invention being described below.

Fig. 4 shows an application of this invention for comparing by means of a pilot circuit, such as a telephone line, the phase angle between two voltages V_1 and V_2 originating at different sources or stations A and B. The voltage V_1 is transmitted from station A over the pilot line 100 to station B at the distant end of the pilot line where another voltage V_2 is to be compared with the voltage V_1 by means of a phase angle meter 200, to determine the difference in phase between the two voltages V_1 and V_2 . The voltage V_1 generated at station A is impressed upon the pilot line 100 and transmitted to the distant end at station B where the voltage is taken off from the pilot line through series resistances R_1 and R_2 which must have a high resistance in comparison with the impedance of the line and of the terminating impedances Z_T . In order that the phase angle between the voltages V_1 and V_2 may be obtained from the readings of the phase angle meter 200, it is, of course, necessary to correct for any change in phase of voltage V_1 which may be introduced by the line 100. This may be accomplished by measuring the phase change caused by the line itself between proper impedances Z_T at each end of the line. This phase change caused by the line must then be subtracted from the indication given by the phase angle meter in order to obtain the true phase difference between the voltages V_1 and V_2 . The phase change caused by the line itself may be measured by any of the well-known methods, for example, that shown in W. P. Mason Patent 1,684,403, issued September 28, 1928. The phase change caused by the line itself will change with weather variations and the like and this may be minimized in accordance with this invention by

terminating the ends of the line with similar impedances Z_r , the value of which may be calculated as explained above, particularly in describing Figs. 1 and 2.

5 Figs. 4A and 4B show alternative arrangements for connecting the source of alternating voltage to the line circuit 100. In Fig. 4A the coupling is a transformer so designed that the impedance Z_r looking into the line side of the transformer is of the proper value for terminating this end of the line for effecting the desired reduction of phase variations therein. In Fig. 4B the coupling is also a transformer and, in addition, separate impedances are inserted in the line to build up the impedance Z_r looking into the line side thereof to afford the proper impedance.

Fig. 5 also shows an application of this invention for comparing by means of a pilot line, the phase angle between two voltages V_1 and V_2 , at stations A and B, respectively, in a manner similar to that described in Fig. 4 but without the necessity of separately measuring the phase change caused by the line itself, since in this arrangement a phase compensator 300 is employed to compensate for phase changes in the line. The action of the phase compensator 300 is such that the phase angle meter 200 is held at zero indication when the voltages V_1 and V_2 are in phase. The phase compensator may consist of a network composed of one or more of the following elements, resistances, inductances, and capacitances. The design of such networks is well known in the art. See, for example, H. Nyquist Patent 1,770,422, July 15, 1930. With this arrangement wherein the phase change introduced by the line is corrected the phase angle meter always directly indicates the phase angle between voltages V_1 and V_2 . The general description of Fig. 4 is obviously applicable to this figure.

40 Fig. 6 shows another application of this invention wherein it is employed for measuring the phase angle difference between two different power systems or two different points on the same power system. The two different power systems A and B or the two different points on the same power system are connected through suitable coupling means by a pilot circuit for comparing the phase relationship of the two systems or points on the same system. The power systems, or system, are shown as three-phase systems and the pilot circuit 100 is connected at two selected points A and B by means of suitable coupling elements across one phase of the power line. Measuring the phase difference between the two points in one phase of a polyphase system may be sufficient when the several phases are substantially balanced, but if phase angle measurements for the other phases of a polyphase system are desired, they may be made for the other phases of the power system either by employing a pilot circuit for each phase or by having switching devices for synchronously switching the pilot circuit connections from one phase to another of the power system. The arrangement here shown is similar to that of Fig. 5 for measuring the phase angle between two sources of voltage and is here applied to measure the phase angle between the two points on one phase of the power system or systems A and B, irrespective of the location of the source or sources of power. The series resistances R_1 and R_2 must be high in comparison with the terminating impedance Z_r at each end of the pilot circuit. The phase compensator 300 compensates for any phase displacement caused by the pilot circuit and consequently the readings

of the phase angle meter 200 show directly the phase difference between the voltages of the different power systems.

Fig. 7 shows a further application of this invention as applied to power transmission for automatically maintaining two different power systems or two different points in the same power system in phase. The arrangement here shown is similar to that of Fig. 6 but employs in addition automatic means for adjusting the phase relationship of one system to that of another system so that they may be automatically maintained substantially in phase with one another. A different relay arrangement 400 is here substituted for the phase angle meter measuring arrangement shown in Fig. 6 which automatically operates when there is a difference in phase between the two systems A and B. When a relative phase change occurs in one direction, the relay closes a circuit which operates an adjusting mechanism 500 connected with local control apparatus to cause a shift in the proper direction of the phase in the local system, and when the relative phase change is in the opposite direction, the relay closes another circuit which causes a shift in the opposite direction of the phase of the local system, thereby automatically causing a phase change in the local system to substantially eliminate the phase difference between the systems. The differential relay arrangement 400, as here shown, consists of two vacuum tubes 401 and 402 in push-pull arrangement and so connected that the output circuit of each tube controls the energization of one side of a differential relay 410 which in turn operates the phase adjusting mechanism 500, and thus maintains a balance in the phase relationship of the systems. The input circuits of this differential relay arrangement are connected by suitable coupling transformers with the pilot circuit 100 interconnecting the power systems A and B and with a local circuit associated with the power system B. The adjusting mechanism 500 which may be mechanically connected to the local control apparatus for adjusting the phase relationship of the local system to that of the other system may be of any suitable type such as is now used and mechanically operated for changing the phase relationship of a power system with that of another such system. Fig. 7, as above stated, relates primarily to the automatic control of the relationship rather than to the mechanism operating the local control apparatus. The adjusting mechanism may be of any suitable type such, for example, as that shown in Patent 1,703,142 to E. I. Green, especially Fig. 2a in which relay 32 may correspond to relay 410 of the present application.

All of these applications are made practicable by providing a circuit of substantially constant phase relation.

This invention may be applied to any line, within the limits outlined above, for which the phase characteristic is required to be substantially constant.

While this invention has been disclosed as embodied in certain particular forms, it is to be understood that it is not limited to such forms but is capable of embodiment in other forms without departing from the spirit and scope of the appended claims.

What is claimed is:

1. In combination with an electrical system, means for measuring the phase difference of the voltages at two points on said system, which consists of a pilot circuit between the two said points,

- means for compensating for variations in phase displacement in said pilot circuit by terminating both ends with equal impedances having large values compared with one-half the series impedance of the equivalent T-network of said pilot circuit, coupling means for impressing the voltage at one of said points upon said pilot circuit, and means associated with said pilot circuit for measuring the phase angle between said voltages.
2. In combination with a power system, means for measuring the phase difference of the voltages at two points on said system, which consists of a pilot circuit between the two said points, said pilot circuit being terminated at both ends with equal impedances having large values in comparison with one-half the series impedance of the equivalent T-network of said circuit, coupling means for impressing the voltage at one of said points of said power system upon said pilot circuit, and means at the other end of said pilot circuit for measuring the phase angle between the voltage at the other of said points on said power system and that impressed on said pilot circuit.
3. In combination with a power system, means for measuring the phase difference of the voltages at two points on said system, which consists of a pilot circuit between the two said points, said pilot line being terminated at both ends with equal impedances having large values in comparison with one-half the series impedance of the equivalent T-network of said circuit, coupling means for impressing the voltage at one end of said points of said power system upon said pilot circuit, means for compensating for phase displacement in said pilot line, and means at the other of said points of said power system for measuring the phase angle between the voltage at the said other point on said power system and that impressed on said pilot circuit.
4. In combination with a power system, means for comparing the phase difference of the voltages at different points on said system, which consists of a pilot line between said points, said pilot line being terminated at both ends with equal impedances having a value large in comparison with one-half the series impedance of the equivalent T-network of said circuit, coupling means for impressing the voltage at one of said points upon said pilot line, means for compensating for phase displacement in the said pilot line, means including said pilot line connecting between the said points of said system for comparing the phase angle between said voltages, and means controlled by said comparing means for automatically adjusting the phase relationship of said voltages so that the phase angle between said voltages is substantially nil.
5. In combination with a power system, means for comparing the phase difference of the voltages at different points on said system, which consists of a pilot line between the said points, said pilot line being terminated at both ends with equal impedance having the value large in comparison with one-half the series impedance of the equivalent T-network of said circuit, coupling means for impressing the voltages at one of the said points upon said pilot line, means for compensating for phase displacement in the said pilot line, means including said pilot line connecting between said points of said system for comparing the phase angle between said voltages, and means controlled by said comparing means for automatically adjusting the load at the two points in said power system in accordance with the phase angle between the said voltages.
6. In combination with a polyphase power system, means for measuring the phase difference of the voltages at two points on said system which consists of a pilot line between the said points, coupling means for impressing the voltage of the power circuit at two of said points upon said pilot line, means for compensating for variations in phase displacement in the said pilot line, and means including the said pilot line on said system for controlling the phase angle between said voltages at each of said points of said power system.
- NEWTON MONK.