

July 13, 1937.

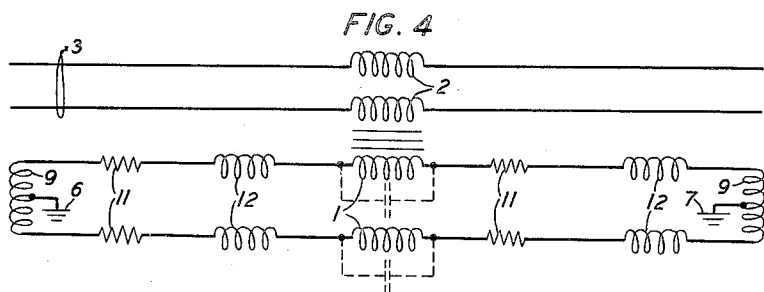
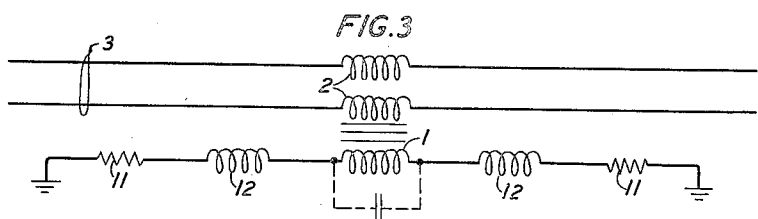
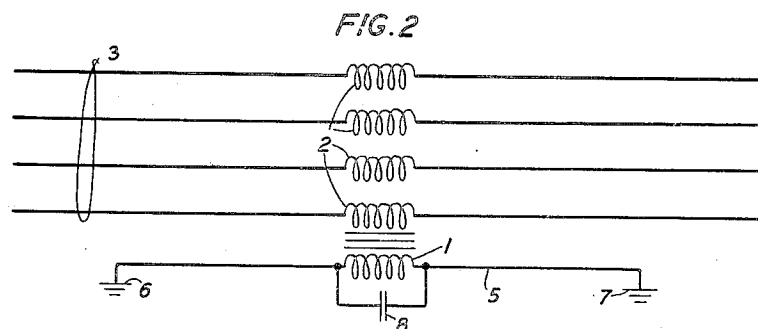
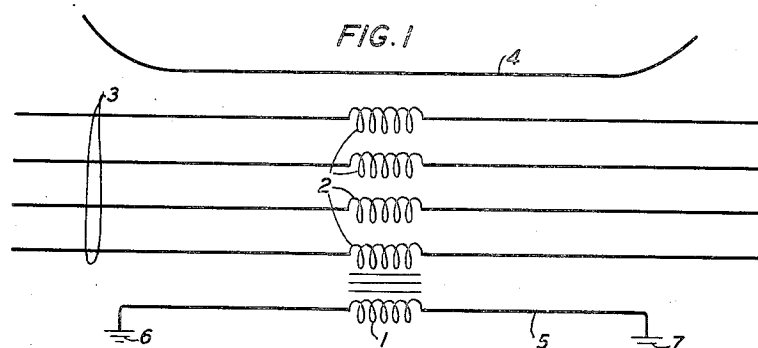
C. C. CASH

2,086,603

NEUTRALIZING SYSTEM

Filed Jan. 31, 1936

3 Sheets-Sheet 1



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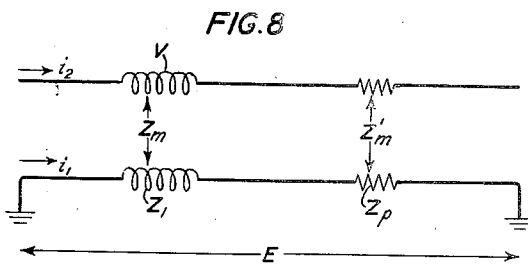
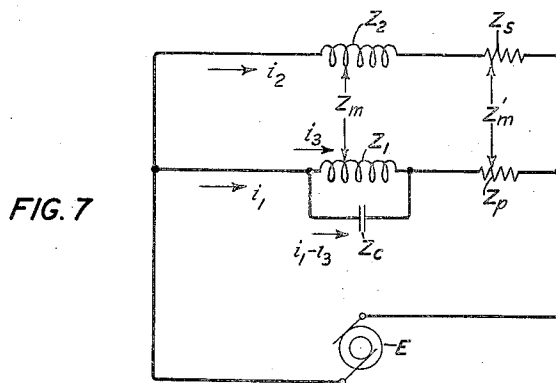
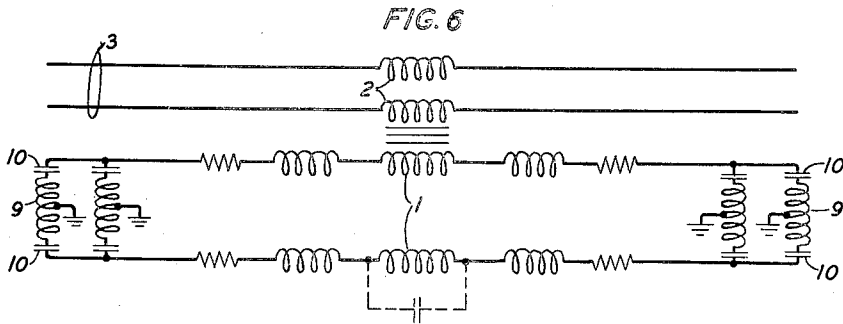
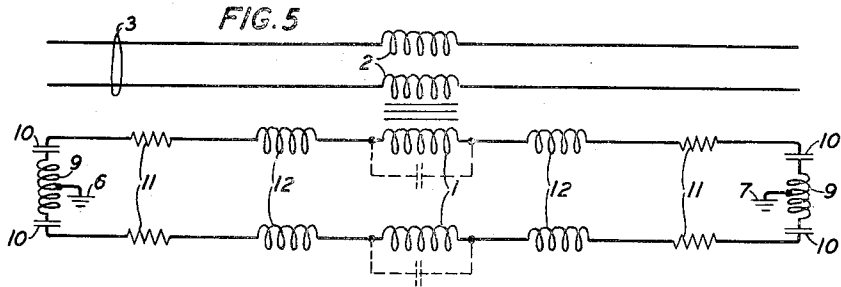
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NEUTRALIZING SYSTEM

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3 Sheets-Sheet 2



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NEUTRALIZING SYSTEM

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3 Sheets-Sheet 3

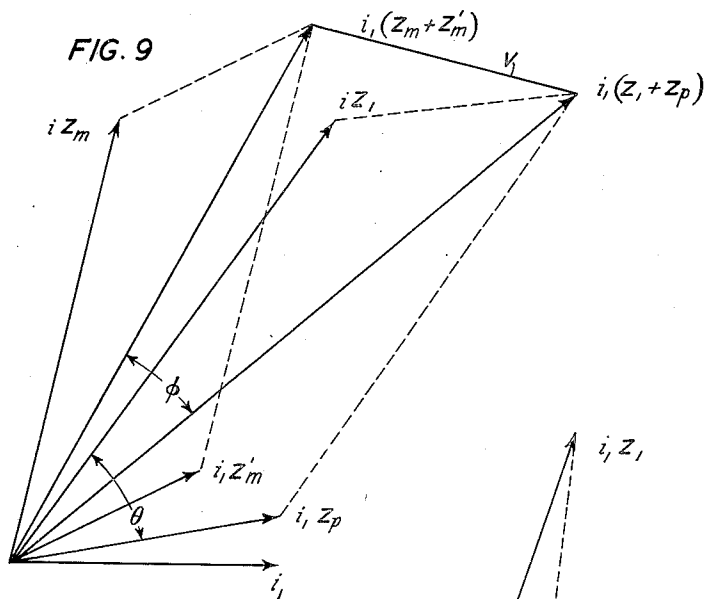
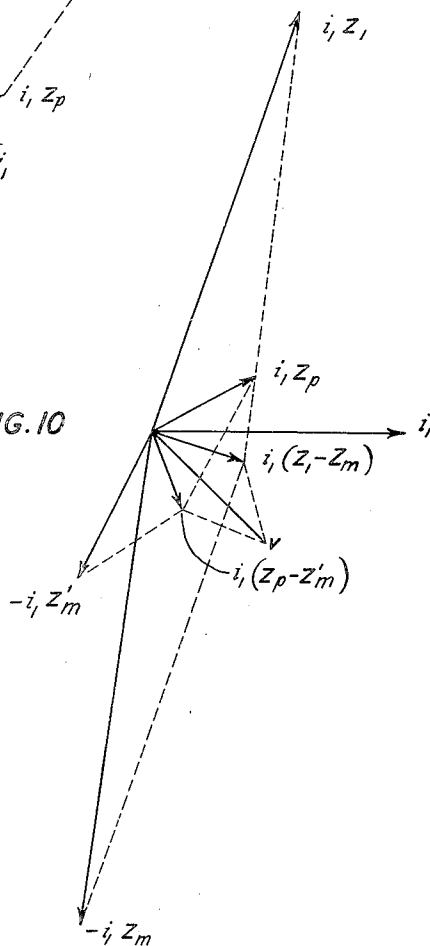


FIG. 10



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UNITED STATES PATENT OFFICE

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NEUTRALIZING SYSTEM

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Application January 31, 1936, Serial No. 61,838

11 Claims. (Cl. 171—97)

This invention relates to neutralizing systems and particularly to means for and the method of neutralizing disturbances in communication circuits.

Heretofore neutralizing transformers have been applied to groups of communication conductors for suppressing or neutralizing the extraneous voltages induced therein from neighboring power lines or other disturbing circuits to which the communication circuits are exposed. In the application of these neutralizing transformers the primary windings are connected in an auxiliary circuit and the secondary windings in the communication circuits, the same disturbances being induced in both the auxiliary circuit and the communication circuits, these secondary windings being so related to the primaries that the voltages induced therein by the primary windings tend to oppose those induced directly by the power or disturbing circuit into the communication circuits.

In a neutralizing transformer arrangement of this kind the primary and secondary circuits have a certain amount of self and mutual impedance. The transformer primary winding is so constructed that its impedance is a large part of the total primary circuit impedance, and this is largely inductive when a winding alone is used, but can be changed to a largely resistive impedance by using a tuning condenser across the winding. The mutual impedance between the primary and secondary windings is approximately the same as the primary self-impedance. The primary circuit external to the transformer winding has a certain amount of self-impedance, and there is also a mutual impedance existing between it and the communication circuits used as secondary wires. In the neutralizing transformer system, the currents and voltages are dependent on these impedance values and relationships. Heretofore transformers have been built and installed in the communication circuits without special attention being given to the effects of these self and mutual impedances on the voltage remaining in the secondary circuits. For high induced voltages it is more difficult to obtain satisfactory neutralization. As the induced voltages become higher so must the efficiency of neutralization increase in order to meet the communication service requirements. When the induction is in the order of magnitude of 1000 volts or more, and with present methods of connecting the transformers in the circuits, unneutralized voltage may be large enough to interfere with communication over the wires.

It is therefore the object of this invention to obtain a more complete neutralization of the extraneous electromotive forces than has been possible heretofore and to accomplish this purpose with methods and apparatus which are simple and inexpensive.

A feature of the invention is a method of neutralizing extraneous voltages in a communication circuit in which the primary winding of a neutralizing transformer is connected in a primary line and the secondary winding is connected in the communication circuit (secondary line), and in which the self impedance of the primary winding and of the primary line together with the mutual reactances of the transformer and of the primary and secondary lines are so chosen in magnitude and in their relation to each other that the unneutralized voltage in said secondary line is reduced to a minimum.

Another feature is to obtain the proper relation between the impedance components of the system which determine the value of unneutralized voltage by varying the amounts of resistance, inductance, and capacitance, in the primary line or by varying one or more of these factors.

Another feature is to connect the primary line to ground on both sides of the transformer by means of balanced drainage bridges comprising inductance coils, condensers, or both, said coils and condensers serving as part of the impedance in the primary line necessary to give the neutralization above mentioned.

The foregoing and other features of the invention will be described more fully in the following detailed specification and will also be set forth in the appended claims.

My invention is illustrated by the accompanying drawings, in which:

Fig. 1 is a diagram showing the application of neutralizing transformers to communication circuits for the neutralization and suppression of induced voltage effects in said circuits;

Fig. 2 shows the application of a tuning condenser across the primary winding to obtain certain impedance relationships between the primary winding and the auxiliary primary circuit;

Figs. 3, 4, 5, and 6 show means of connecting resistance and reactance in the auxiliary primary circuit, and, in the case of two primary wires, between the ground points and line wires;

Figs. 7 and 8 show equivalent circuit arrangements for the purpose of mathematical calculations; and

Figs. 9 and 10 are vector diagrams showing the different voltage components involved in the system.

The relative impedances of the component parts of the primary and secondary lines are, as has already been stated, important in determining the amount of neutralization secured in the secondary line. The total extraneous electromotive forces induced, respectively, in the primary and secondary lines are in phase and are substantially equal in magnitude. The extraneous electromotive force in the primary line has a component due to the impedance drop of the primary winding of the transformer and other components due to the impedance of the remainder of the primary circuit. It is the first of these components that causes the induced electromotive force in the secondary winding that is relied upon to neutralize the extraneous voltage. The said component in the primary winding and the voltage it produces in the secondary winding are substantially 180 degrees out of phase; therefore, the more nearly this component in the primary winding can be brought into phase with the extraneous electromotive force, and the more nearly equal the magnitude of the voltage induced in the secondary can be made to said extraneous electromotive force the more complete will be the neutralization. I have found, as will be shown later, that the unneutralized portion of the extraneous voltage depends in value upon a number of component voltages. These are the impedance drop in the primary winding of the transformer, the voltage due to the mutual reactance between the primary and secondary windings, the impedance drop in the primary line exclusive of the transformer, and the voltage due to the mutual reactance between the primary and secondary lines exclusive of the transformer windings. The unneutralized voltage is equal to the sum of these four components, two of which are positive and the other two of which are negative in sign. And since the primary winding impedance and the mutual reactance of the transformer which determine two of the four components are more or less fixed by the construction of the transformer, I find it advantageous to attain the desired result above mentioned by varying the other two voltage components, which are determined by the self impedance of the primary line and the mutual impedance between the primary and secondary lines. These variations may be made by the simple act of adding resistance, inductance, and capacity, or different combinations of these to the primary circuit external to the transformer, or by changing the mutual impedance. Also it may be advantageous to obtain the desired relationship by inserting an auxiliary transformer in the primary and secondary circuits. And, as will appear later, by selecting the proper relation between the impedances, the phase angle between the resultant of one pair of the above-noted voltage components and the resultant of the other pair of said components may be decreased, thus reducing the magnitude of the unneutralized voltage which is derived from these two resultants.

Referring now particularly to the drawings, Fig. 1 shows a neutralizing transformer having secondary windings 2 connected in a group of communication wires 3 which are exposed to a power line 4. The transformer primary winding 1 is connected in series relation with an auxiliary circuit 5, which runs parallel and adjacent to the

communication circuits and is connected to ground points 6 and 7 at the ends of the power exposure. The primary winding may be designed so as to have a high inductance, or, as shown in Fig. 2, there may be a tuning condenser 8 connected across the winding, thus making a circuit which is anti-resonant at the disturbing frequency, this circuit having a high resistance component. In both cases the impedance of the primary winding is large compared to the rest of the circuit, wherefore most of the induced voltage appears across the winding. The use of a condenser is made possible by building a transformer with one or more air-gaps so as to make the reluctance more constant through a wide range of flux densities. Therefore, with a transformer having practically a constant value of inductance, there is permitted the effective use of a condenser as a phase controlling device. An increase in the air-gaps, of course, produces a decrease in the inductance of the winding. This is compensated for by increasing the value of the tuning condenser. Adjustment of the air-gaps assists in obtaining the value of inductance which best suits the particular conditions applying for a given transformer.

The auxiliary primary circuit 5 may be a single wire, two wires, or any other arrangement of conductors which will give the correct impedance relations with other parts of the circuit. When two wires are used, they may be connected to ground points 6 and 7 directly or through retardation coils 9, or through retardation coils with series condensers 10 as shown in Figs. 5 and 6. And where cables are involved, either or both of the ground points 6 and 7 may be connected to the cable sheath. When connected to ground through retardation coils, alone or in series with condensers, the wires can be used for communication purposes, while at the same time permitting a means of adjusting the impedance of the auxiliary circuit. These retardation coils may or may not have a high leakage reactance depending on what impedance relationship is desired. It will also be understood that the magnitude and phase of the auxiliary primary circuit impedance drops can be varied by means of resistance 11 and reactance 12 in the auxiliary primary wire or wires, as shown in Figs. 3, 4, 5, and 6. Where the disturbing voltage has a large harmonic component, a plurality of bridges may be used as shown in Fig. 6. One bridge is tuned to the fundamental and the associated bridge or bridges to the prevailing harmonic frequencies of the disturbing voltage.

The effects of the self and mutual impedances of the primary and secondary circuits on the voltage remaining in the communication circuits can best be described in terms of the equivalent circuit of Fig. 7, where

Z_1 =self-impedance of the primary windings,
 Z_2 =self-impedance of the secondary windings,
 Z_c =self-impedance of the tuning condenser,
 Z_p =self-impedance of the auxiliary primary circuit (external to the transformer),
 Z_s =self-impedance of secondary wires external to transformer),
 Z_m =mutual impedance of transformer,
 Z'_m =mutual impedance between auxiliary primary circuit and communication conductors,
 E =voltage induced due to disturbing power circuit,
 V =voltage remaining in the communication circuits.

Writing the voltage drops for the various meshes, there is obtained the following equations:

$$E = i_1 Z'_m + i_3 Z_m + i_2 (Z_2 + Z_s) \quad (1)$$

$$O = i_1 (Z'_m - Z_p) + i_2 (Z_2 + Z_s - Z_m - Z'_m) + i_3 (Z_m - Z_1) \quad (2)$$

$$O = -i_1 Z_c + i_2 Z_m + i_3 (Z_1 + Z_c) \quad (3)$$

Solving for i_1 , we obtain

$$i_1 = \frac{E[Z_1(Z_2 + Z_c - Z'_m) + Z_c(Z_2 + Z_s - Z_m - Z'_m) - Z_m^2]}{D} \quad (4)$$

where

$$D = Z_p Z_c (Z_2 + Z_s) + Z_1 (Z_p + Z_c) (Z_2 + Z_s) - 2Z'_m Z_m Z_c \quad (5)$$

$$- Z_m^2 (Z_p + Z_c) - Z'^m_2 (Z_1 + Z_c) \quad (6)$$

Solving for i_2 , we obtain

$$i_2 = \frac{-E[(Z'_m - Z_p)(Z_1 + Z_c) + Z_c(Z_m - Z_1)]}{D} \quad (7)$$

From the circuit it is seen that the voltage remaining in the communication circuits is

$$V = i_2 Z_s = \frac{EZ_s[Z_c(Z_1 - Z_m) + (Z_1 + Z_c)(Z_p - Z'_m)]}{D} \quad (8)$$

Dividing numerator and denominator by Z_s , and letting $Z_s = \infty$, which would be the condition for open circuit unneutralized voltage, there is obtained the following equation:

$$V = \frac{E[Z_c(Z_1 - Z_m) + (Z_1 + Z_c)(Z_p - Z'_m)]}{Z_p Z_1 + Z_p Z_c + Z_c Z_1} \quad (9)$$

which represents the open-circuit voltage remaining in the secondary circuits. Observing this equation, we see that in order to obtain a minimum V , Z_1 should equal Z_m and Z'_m should equal Z_p . For an ideal transformer where $Z_1 = Z_2 = Z_m$ and $Z_c = -Z_1$, the voltage V equals zero. For any given transformer with constants Z_1 , Z_2 , Z_c and Z_m not equal, the voltage can be reduced to a minimum (as obtained by Equation 9) by the proper choice of the external primary circuit impedance Z_p and the mutual impedance between primary and secondary wires Z'_m .

For neutralizing transformer systems where no tuning condenser is used across the primary winding, the voltage V can be obtained from the above equation, by letting Z_c equal ∞ , in which case we obtain the following value of V :

$$V = \frac{E[(Z_1 - Z_m) + (Z_p - Z'_m)]}{Z_p + Z_1} \quad (10)$$

Thus, we see that in this case, too, the voltage V can be made a minimum by making Z_1 equal Z_m and Z'_m equal Z_p .

A further proof of the effect of circuit impedances on the value of V is illustrated by the circuit analysis using Fig. 8.

Writing the equation for E , we have

$$E = i_2 (Z_m + Z'_m) \quad (11)$$

Also we may express the current i_1 as follows:

$$i_1 = \frac{E}{Z_1 + Z_p} \quad (12)$$

Substituting for E in (12),

$$i_1 = \frac{i_2 (Z_m + Z'_m)}{Z_1 + Z_p} \quad (13)$$

Writing the equation for V , there results

$$V = E - i_1 (Z_m + Z'_m) \quad (14)$$

Substituting Equation (11) in (14),

$$V = i_2 (Z_m + Z'_m) - i_1 (Z_m + Z'_m) \quad (15)$$

From Equation (13) we obtain

$$i_2 = \frac{i_1 (Z_1 + Z_p)}{(Z_m + Z'_m)} \quad (16)$$

and substituting (16) in (15) we obtain as the voltage in the secondary circuit

$$V = i_1 (Z_1 + Z_p) - i_1 (Z_m + Z'_m) \quad (17)$$

From Equation (17) it will be seen that with Z_1 and Z_m more or less fixed by transformer design, the two factors Z_p and Z'_m may be varied to make V a minimum. Thus, if Z_1 is large, thereby making the term $i_1 (Z_1 + Z_p)$ large, we would offset it by making Z'_m large. This is effected by increasing the magnitude of the mutual impedance between the primary and secondary lines. Again, if Z_m of the second term is large, we would increase Z_p of the first term. To do this, impedance is added to the primary line. Since the factors Z_1 and Z_m represent the self-impedance of the transformer primary and the mutual impedance of the primary and secondary windings, the value of the equation may also be controlled by constructing the transformer to give the best values of Z_1 and Z_m for the particular system in which the transformer is to be used. Also, by making the transformer with relatively high values for Z_1 and Z_m it may be applied efficiently to any neutralizing system by so selecting the resistance and reactive components of impedances Z_p and Z'_m as to obtain for these impedances the magnitude and phase relationships which result in a minimum value of the unneutralized voltage V .

To still further explain this neutralizing method, reference is now made to the vector diagrams of Figs. 9 and 10. Fig. 9 shows the four voltage factors on the right-hand side of Equation (17) expressed as vectors. Combining the two vectors $i_1 Z_1$ and $i_1 Z_p$ corresponding to the first term, we obtain the resultant vector $i_1 (Z_1 + Z_p)$. Similarly, by combining the other two vectors we have the resultant vector $i_1 (Z_m + Z'_m)$. Since the two terms of Equation (17) are joined by the minus sign, we take the vectorial difference of vectors $i_1 (Z_1 + Z_p)$ and $i_1 (Z_m + Z'_m)$ to obtain the vector V . This represents the unneutralized voltage. From this diagram it is seen that by decreasing the angle θ between $i_1 Z_1$ and $i_1 Z_p$ the angle ϕ is also decreased, thus decreasing the value of V . This can be accomplished by increasing the inductive reactance component of Z_p , that is, by adding inductance in the primary line.

Equation (17) may also be expressed thus:

$$V = i_1 (Z_1 - Z_m) + i_1 (Z_p - Z'_m) \quad (18)$$

In this case the factors Z_m and Z'_m are negative, and the two terms of the equation are joined by the positive sign. The diagram of Fig. 10 shows the relation of the vectors when V is expressed as in Equation (18). Here the vector V is the sum of the two vectors $i_1 (Z_1 - Z_m)$ and $i_1 (Z_p - Z'_m)$.

What is claimed is:

1. The method of neutralizing an extraneous voltage in a transmission line which comprises

exposing an auxiliary line to said voltage, connecting the primary and secondary windings of a neutralizing transformer in said auxiliary line and in said transmission line, respectively, and
 5 effecting a reduction of the unneutralized voltage by changing the values of the impedances which correspond respectively to the different components of said unneutralized voltage.

2. The combination in a neutralizing system of
 10 a primary line and a secondary line, both of which have extraneous electromotive forces therein, a neutralizing transformer having one winding in said primary line and another winding in said secondary line, and reactive means
 15 included in said primary line to bring the electromotive force induced in the winding in said secondary line by the winding in said primary line into opposing phase relation with said extraneous electromotive force.

3. The combination in a neutralizing system of a secondary line, a primary line comprising two conductors, reactance bridges across said conductors at each end of said primary line, a
 25 neutralizing transformer having a secondary winding in said secondary line and primary windings in said primary conductors, both primary and secondary lines being exposed to a source of extraneous electromotive force, and impedance
 30 elements in said primary conductors, the impedance value of said elements and of said bridges being so proportioned with respect to the impedance of said transformer that a maximum neutralization of said extraneous voltage is
 35 effected.

4. The combination in a neutralizing system of a primary line and a secondary line, both of which have extraneous electromotive forces induced therein, a neutralizing transformer having
 40 its primary winding in said primary line and its secondary winding in said secondary line, and impedance means in said primary line including both reactance and resistance for causing the phase angle between the electromotive force induced
 45 in said secondary winding from said primary winding and the extraneous electromotive force in said secondary line to approach 180 degrees.

5. The combination in a neutralizing system of a primary circuit and a secondary circuit, both
 50 of which are subject to extraneous electromotive forces from the same source, a neutralizing transformer having a primary winding in said primary circuit and a secondary winding in said secondary circuit, drainage bridges on either side
 55 of said primary winding for connecting the conductors of said primary circuit to ground to permit flow of current through the primary winding as a result of the extraneous electromotive force, and reactive means connected in said primary
 60 circuit external to the primary winding of said transformer for controlling the phase relation of said extraneous electromotive force and the electromotive force induced in the secondary winding of said transformer from said primary
 65 winding.

6. The method of neutralizing an extraneous voltage in a secondary line which comprises exposing a primary line to said voltage, connecting
 70 the primary and the secondary windings of a neutralizing transformer respectively in said primary and said secondary lines, substantially neutralizing said extraneous voltage and leaving in said line a residue of unneutralized voltage having
 75 a number of components one of which is pro-

portional to the impedance of said primary line, and reducing said unneutralized voltage to a minimum by adding elements to said primary line to increase the magnitude of the impedance thereof.

7. The method of neutralizing an extraneous voltage in a secondary line which comprises exposing a primary line to said voltage, connecting the primary and secondary windings of a neutralizing transformer respectively of said primary and secondary lines, substantially neutralizing said extraneous voltage and leaving an unneutralized voltage having a number of components, one of which is proportional to the impedance of said primary line, and another of which is proportional to the mutual impedance
 15 of said primary and said secondary lines, and reducing said unneutralized voltage to a minimum by varying the values of said impedances.

8. The method of neutralizing an extraneous voltage in a secondary line which comprises exposing a primary line to said voltage, connecting the primary and secondary windings of a neutralizing transformer respectively in said primary and secondary lines, partly neutralizing said extraneous voltage and leaving in the line a residue of unneutralized voltage having a number of components, one being proportional to the impedance of said primary winding, another to the mutual impedance of said windings, another to the impedance of said primary line, and another to the mutual impedance of said lines, and reducing said unneutralized voltage to a minimum
 30 by adding impedance elements to increase the magnitude of said primary line impedance and said mutual line impedance.

9. The method of neutralizing an extraneous voltage in a secondary line which comprises exposing a primary line to said voltage, connecting the primary and the secondary windings of a
 40 neutralizing transformer respectively in said primary and said secondary lines to neutralize a substantial part of said extraneous voltage, the remaining unneutralized portion of said extraneous voltage having a number of components, and
 45 effecting a reduction of said unneutralized voltage by adding impedances to said primary line to change the phase angles of said components.

10. The method of neutralizing an extraneous voltage in a secondary line which comprises exposing a primary line to said voltage, connecting the primary and the secondary windings of a neutralizing transformer respectively in said primary and said secondary lines, to neutralize a substantial part of said extraneous voltage, the unneutralized part of said voltage having a number of voltage components each of which is proportional to a corresponding impedance, and reducing said unneutralized voltage to a minimum
 60 by adding elements to increase the magnitude of said impedances and to change the reactive components thereof.

11. The combination in a neutralizing system of a primary circuit comprising a plurality of conductors and a secondary circuit, both of said circuits being subject to extraneous electromotive forces from the same source, a neutralizing transformer having primary windings connected to the conductors of said primary circuit and a secondary winding in said secondary circuit, drainage bridges on either side of said primary windings for connecting the conductors of said primary circuit to ground to permit the flow of current through said primary windings as a re-
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sult of the extraneous electromotive force, said
bridges including both inductive and condensive
reactance elements, and reactive and resistive
elements connected in said primary circuit ex-
5 ternal to the primary windings of said trans-
former, the elements of said bridges and said

primary circuit serving to control the phase re-
lation of said extraneous electromotive force and
the electromotive force induced in the secondary
winding of said transformer from said primary
windings.

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