

Feb. 18, 1941.

J. D. BROWDER ET AL

2,232,364

MEANS FOR UTILIZING A ZERO-PHASE SEQUENCE NETWORK

Filed Sept. 5, 1939

3 Sheets-Sheet 1

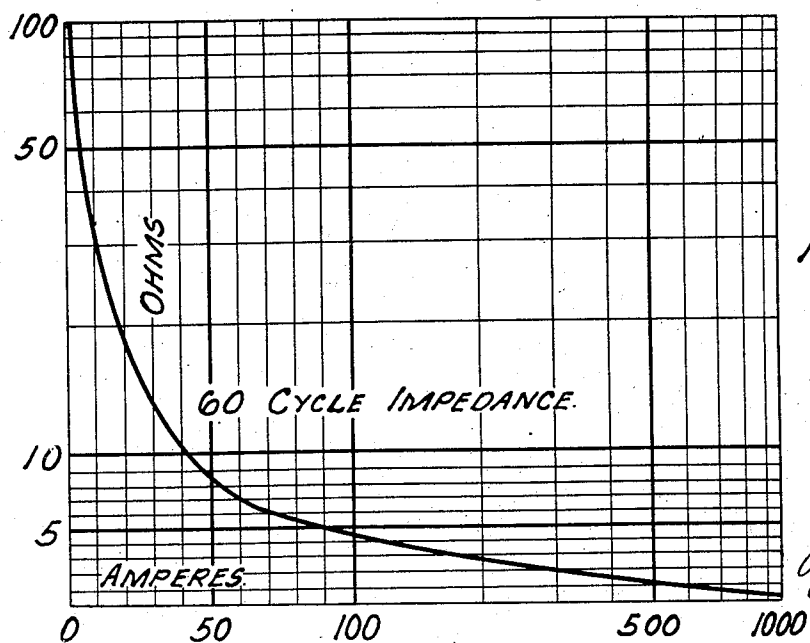
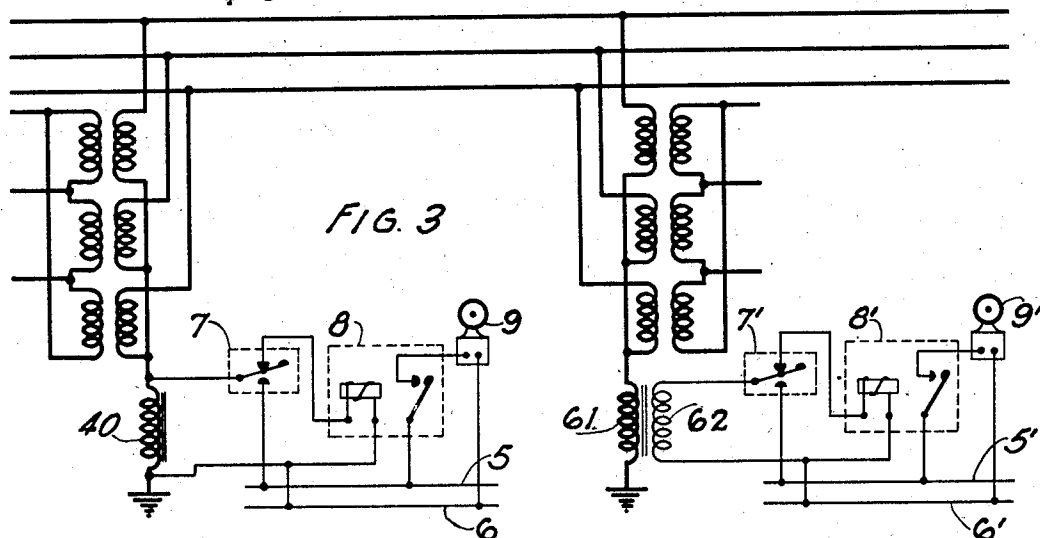
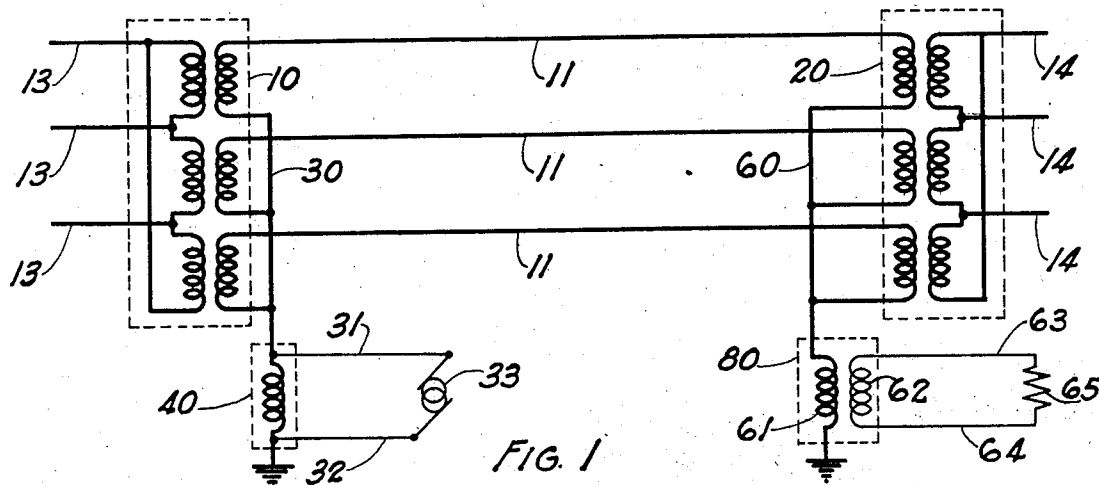


FIG. 2

INVENTORS

Jewel D. Browder
Donald C. Harder

Feb. 18, 1941.

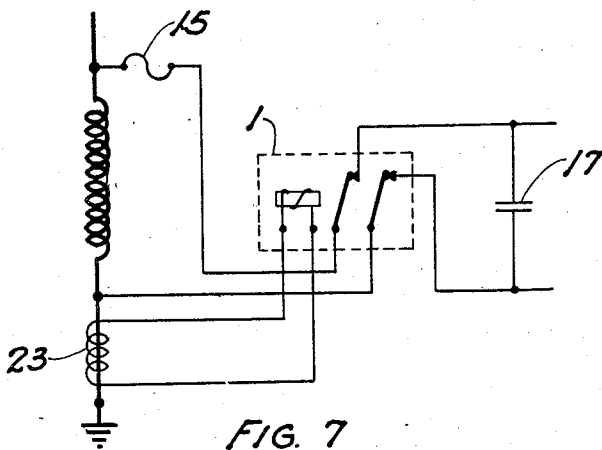
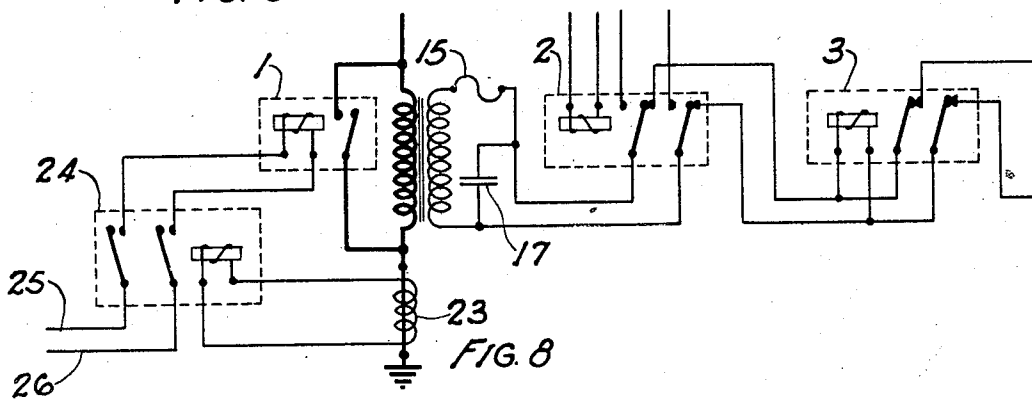
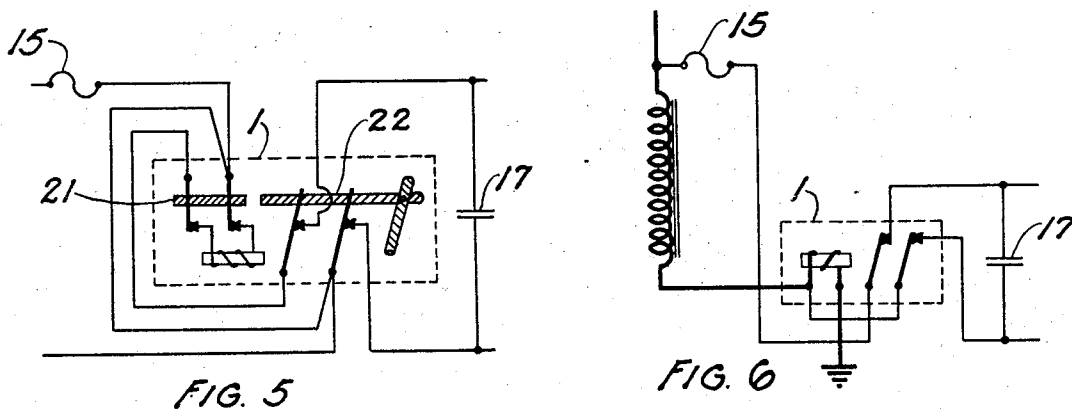
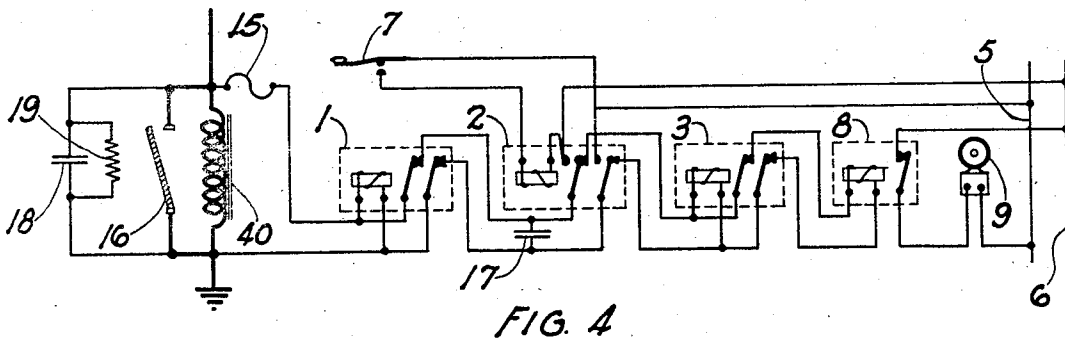
J. D. BROWDER ET AL

2,232,364

MEANS FOR UTILIZING A ZERO-PHASE SEQUENCE NETWORK

Filed Sept. 5, 1939

3 Sheets-Sheet 2



INVENTORS

Jewel D. Browder
Donald C. Harder

Feb. 18, 1941.

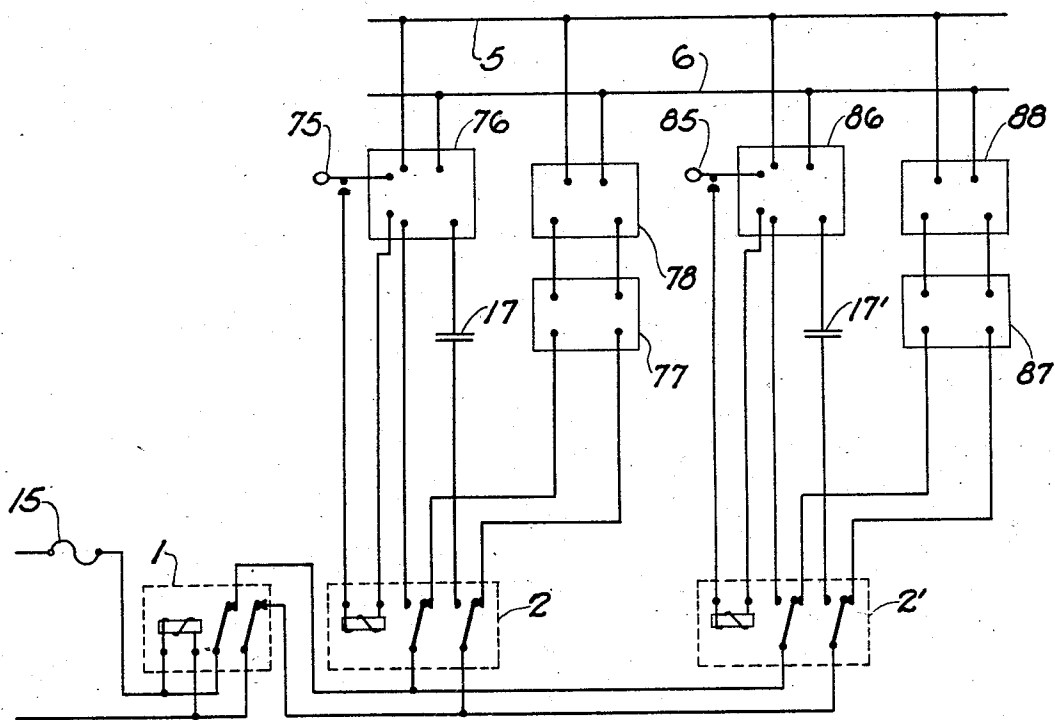
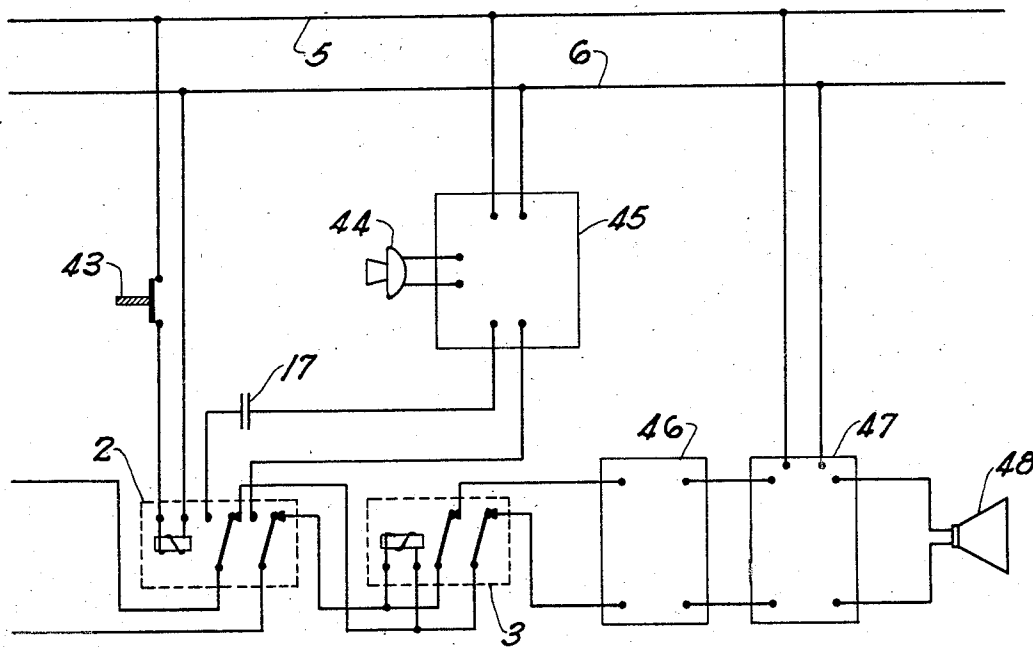
J. D. BROWDER ET AL

2,232,364

MEANS FOR UTILIZING A ZERO-PHASE SEQUENCE NETWORK

Filed Sept. 5, 1939

3 Sheets-Sheet 3



INVENTORS

Jewel S. Browder
Donald C. Harder.

UNITED STATES PATENT OFFICE

2,232,364

MEANS FOR UTILIZING A ZERO-PHASE
SEQUENCE NETWORKJewel D. Browder and Donald C. Harder, Okla-
homa City, Okla., assignors of one-tenth to
David O. Lima, Oklahoma City, Okla.

Application September 5, 1939, Serial No. 293,320

20 Claims. (Cl. 179-2)

One object of our invention is to provide adequate low-energy electrical circuits between desired points along an electric power transmission system, simply by utilizing the zero-phase sequence network of the transmission system itself and thus avoid the expense incident to the use of conventional low-energy circuits of the telephone and telegraph variety.

A further object of our invention is to effect a practical utilization of the zero-phase sequence network of a three-phase multiple grounded-neutral alternating current transmission system in a manner that shall not interfere with either the normal or emergency operation of said electric power system including all of its main and auxiliary components.

Another object of our invention is to employ alternating currents of suitable frequency, or frequencies, in the physical circuit afforded by the zero-phase sequence network in order that a single channel, or a multiplicity of individual channels which can be used simultaneously without mutual interference, may be obtained between any two or more desired points along the electric power transmission system.

Still another object of our invention is to provide suitable over-voltage protection to terminal apparatus of the low-energy circuit, whereby said over-voltage protective devices are caused to function instantly upon the occurrence of a ground fault on the power transmission system.

The utilization of a zero-phase sequence network for the achievement of conventional low-energy services such as signalling, remote metering and control, or telegraphic and telephonic communications between remote points along a transmission system must not be permitted to conflict with the usual safe and regular performance of the power system. Every feature of the utilization which has a direct bearing on the performance of the power transmission system during either its normal or faulted operating condition demands careful analysis and the employment of proper measures for guarding against the establishment of a precarious condition that may lead to disastrous consequences. The great disadvantage of older means for similarly utilizing the zero-phase sequence network, such as disclosed in U. S. Letters Patent 1,771,135, dated July 22, 1930, is the fact that these said means themselves constitute a decided hinderance to safe and satisfactory performance of the power system particularly while a ground fault exists on the transmission system. Said old means are not only hazardous to certain vital equipment of the

power system but also necessitate special auxiliary protective-relay installations.

In practicing this invention, we provide a simple but reliable means for assuring both a high degree of power-system transient stability and the proper functioning of conventional protective relays when a ground fault occurs on the transmission system. These outstanding features have been clearly demonstrated and proved in actual experience with two trial installations, one of which utilizes a 78-mile section of an extensive 66 kv. transmission system, and in both cases the previously existing protective relays have continued to function correctly without necessitating any expensive alterations or additions thereto. Consequently to persons versed in the art of electric power transmission, it will be manifest in the following disclosure that our invention can be economically applied to and safely coordinated with existing transmission systems of the prescribed type for the obvious purpose of providing suitable low-energy circuits which are often indispensable to adequate supervision and control of the electric power system itself.

With the foregoing and other objects in view, this invention consists in the apparatus, systems and methods hereinafter described and claimed, and illustrated in the accompanying drawings, wherein

Figure 1 is a diagrammatic view of a simple two-terminal zero-phase sequence network embodying our invention in effecting practical usage of such a network during normal operating conditions of the electric power transmission system.

Figure 2 illustrates by rectangular coordinate curve the non-linear impedance of special reactor as well as that of neutral winding of special transformer, which is a fundamental element of our invention.

Figure 3 is a diagrammatic view of an elementary signal system affording code signalling between two stations remotely located along the transmission line of an electric power system.

Figure 4 illustrates our invention in equipping low-energy circuit terminal apparatus with practical auxiliary devices for facilitating the maintenance of said terminal apparatus in addition to providing it with automatic service-restoring protection against excessive over-voltages.

Figures 5, 6, 7 and 8 diagrammatically illustrate modifications and other alternative schemes for providing over-voltage protection to terminal apparatus.

Figure 9 is a diagrammatic view of our inven-

tion in utilizing the zero-phase sequence network for telephony or voice communication.

Figure 10 is a similar view of our invention in utilizing the zero-phase sequence network for simultaneous multi-channel signalling, telegraphy, and other low-energy services, or any desired combination of such services as may be accomplished by impulses of alternating current.

In describing our invention we shall first outline briefly some of the major characteristics of the zero-phase sequence network of a three-phase multiple grounded-neutral alternating-current transmission system. Such a system contains two or more Y-connected grounded-neutral transformer banks which are remotely located from each other but directly interconnected by means of the usual three-phase transmission line. Said transformer banks are usually located at generating plants and distant substations where they serve either as step-up or step-down power transformers through which passes the electrical energy supplied to or from said interconnecting high-voltage transmission line. To effect a voltage transformation, each transformer bank generally contains at least one other three-phase winding or grouping of three single-phase windings which are magnetically coupled to and intimately associated with the Y-connected windings that join directly to transmission line conductors, and said winding or grouping of three separate windings is delta connected for reasons of power-system stability and suppression of harmonics. In addition to these Y-connected transformers which permit the establishment of grounded neutrals for the transmission line, actual power systems often employ other transformer banks which are delta connected to the transmission line, but such banks do not constitute a branch or terminal of the transmission line's zero-phase sequence network. Thus the transmission system may contain many branches, with some serving Y-connected transformers and others serving delta-connected transformers. Yet the zero-phase sequence network includes only those branches which may carry current in an earth-return path and, therefore, in general it has a much smaller number of branches than its associated positive-phase sequence network of the same transmission system.

Primarily our invention assumes that Y-connected grounded-neutral power transformers are installed at the various points or stations along the transmission line where it is desired to establish terminals of the low-energy circuit afforded by the zero-phase sequence network. Figure 1 depicts two of said power transformers, 10 and 20, located at different stations and interconnected by the three-phase transmission-line conductors 11. Each transformer bank contains delta-connected windings which are magnetically coupled to associated Y-connected windings as previously described. Said delta-connected windings of transformer bank 10 connect directly to three-phase conductors 13, and said windings of transformer bank 20 connect similarly to three-phase conductors 14, as shown. Each group of three-phase conductors 13 and 14 comprises a separate voltage system which usually is not only of a lower voltage than that of the transmission conductors 11 but also connects directly to either or both the alternators which supply electrical energy and the distribution circuits which carry said energy to the load or energy consuming apparatus; said vital features of the power system are not shown in Figure 1 because they do not

enter into the zero-phase sequence network of transmission conductors 11 and therefore are irrelevant to our invention.

With further reference to Figure 1, it is seen that the Y-connected windings of transformer bank 10 are so connected by means of a neutral bus or single conductor 30, and similarly the said windings of transformer bank 20 necessitate neutral conductor 60. In power systems that serve large areas and consequently employ relatively long transmission lines, it is common practise to extend and electrically connect the neutral conductors 30 and 60 to substantial ground connections located nearby so as to effect minimum series resistance in said ground connections. However, in large-capacity metropolitan power systems serving relatively small areas and highly concentrated loads over short transmission lines, a special resistor or impedance element of comparatively small ohmage is frequently employed in series between the neutral conductor and ground connection of each large transformer bank in order that said series element will reduce the magnitude of ground-fault current and consequently the system disturbance and rupturing duty imposed upon the oil circuit breakers employed for isolating the faulty section from the power system. Whether or not such a neutral resistor is utilized does not matter, as our invention is equally applicable to either mode of grounded-neutral construction and operation as will be hereinafter disclosed.

In series with the neutral and ground, we employ a specially designed reactor 40, or a similar transformer 80, as depicted in Figure 1. Either of said devices may be utilized exclusively, or both in combination as illustrated in Figure 1 where a reactor 40 is installed at one station and a transformer 80 is installed at another station. But it is essential that said devices be specially designed to function with the particular power system to which they are applied so as to provide a safe and reliable means for utilizing the low-energy circuit hereinafter described. If the single winding of reactor 40, or the neutral winding 61 of special transformer 80, offered appreciable impedance to passage of ground-fault current, it would not only be necessary to insulate said windings for withstanding considerable voltages but the transmission system would also have to be equipped with ground-fault relays in order to obtain automatic operation of circuit breakers for isolating ground faults. Moreover, in extensive power systems employing long distance transmission lines, the neutral shift and phase distortion of transmission voltages accompanying a ground fault would be absolutely intolerable. Therefore for these obvious reasons we ascribe certain special properties to said reactor 40 and neutral winding 61 of transformer 80, as hereinafter disclosed.

To avoid the above enumerated and extreme disadvantages to practical operation of the power transmission system, said reactor 40 and neutral winding 61 are constructed for offering minimum impedances to passage of ground-fault current and yet serve as suitable means for applying low-energy circuit apparatus to the zero-phase sequence network. Actually, said reactor 40 and neutral winding 61 have decidedly non linear impedance characteristics, so that an appreciable impedance is offered to passage of power-system frequency low-energy circuit currents of relatively small magnitudes and a decidedly lower impedance to passage of power-system ground-

fault currents of relatively large magnitudes. Such a non linear impedance characteristic is represented by the curve in Figure 2, which shows a varying impedance to 60-cycle current of varying effective magnitude as obtained by actual tests on a neutral winding such as that designated 61 of special transformer 80 in Figure 1. Ordinate of the curve, Figure 2, depict the said non linear impedance with current values plotted as abscissas. Said non linear impedance is so unique and applicable that it not only permits satisfactory operation of the low-energy circuit hereinafter described but it also allows the existing power system including all main and auxiliary equipment to function correctly and without harmful effects during both normal and faulted conditions.

The essentially low range of non linear impedance may be had by properly proportioning the iron core and turns of conductor which enter in the construction of said reactor or neutral winding of special transformer. In the practical design of said reactor or neutral winding of special transformer for installation in the neutral of a given transformer bank, the first requisite is to determine the maximum ground-fault current that is possible to experience in the neutral of said given transformer bank under existing power system conditions. Then, ignoring the fact that the completed reactor or neutral winding will very slightly reduce this maximum value of ground-fault current, a conductor having sufficient cross-sectional area and current-carrying capacity for safely handling said maximum ground-fault current for a reasonable length of time is selected for winding the reactor or neutral winding of special transformer. The insulation of said conductor shall be sufficient to withstand resultant voltage stresses existing throughout the completed winding during passage of said maximum ground-fault current, which voltage stresses ordinarily shall exceed those existing during normal operation of the power system and performance of the low-energy circuit hereinafter described. The number of conductor turns and dimensions of the iron core shall be of the smallest practicable values respectively for assuring adequate performance of the low-energy circuit without experiencing excessive energy losses in said conductor turns and iron core. Preferably the core should magnetically saturate at a relatively low magnitude of power-system frequency current in order that the lowest possible values of impedance may be presented to ground-fault currents of relatively large magnitudes, as depicted by the curve in Figure 2. With such a properly constructed reactor or neutral winding of special transformer, impedances to low amplitude currents of power-system frequency as well as voice frequencies range upward from a minimum of approximately 150 ohms depending, of course, on magnitude and frequency of the current; but when a ground fault occurs on the transmission system the impedance presented to the passage of resultant fault current may be any value ranging downward from a maximum of approximately 10 ohms to as low as $\frac{1}{4}$ ohm depending upon the magnitude of said fault current.

Obviously such low impedances cannot materially decrease the magnitude of fault current and therefore will not materially affect the operation of protective relays previously installed under power-system conditions existing before installing said reactor or special transformer. Also careful consideration will show that no difficulties

are encountered by forcing the normal residual or neutral current to pass through the reactor or neutral winding. Said current has a practically constant magnitude, and flows between the transformer-bank neutral conductor and ground at all times during normal operation of the power system; and it is a well known fact that said current is a composite current consisting of three distinct components, viz., (1) a condensive current of power-system frequency resulting from electrostatic unbalance of the transmission-line conductors, (2) a leakage current also of power-system frequency resulting from imperfect insulation of the transmission conductors, and (3) the triple-frequency group of transformer harmonic-currents consisting of the third harmonic of power-system frequency and some of its higher odd multiples such as, in the case of a 60-cycle system, the ninth, fifteenth, twenty-first, etc., depending largely upon magnetic-circuit characteristics of the particular transformer banks employed.

The application of said reactor or special transformer is not necessarily confined wholly to grounded neutrals of regular power transformer banks as just described. For in certain delta-connected transmission systems where grounding transformers have been installed for reasons of modernization and improved performance during ground-faulted conditions, it is obvious that said grounding transformers may be employed in combination with our reactor or special transformer in a manner identical to that of Y-connected power banks. In such a power system it is well known that said grounding transformers establish a zero-phase sequence network exactly like that existing in a Y-connected multiple grounded-neutral transmission system, although the transmission of power is actually achieved by use of delta-connected transformer windings joined directly to the line conductors.

Having thus described our reactor 40 and neutral winding 61 of special transformer 80, Figure 1, and disclosed that either may be adapted for series installation in grounded neutrals of transformer banks with positively no attendant difficulties or disadvantages which could possibly impair the usual performance of the prescribed power system, we shall now consider the low-energy circuit afforded by the zero-phase sequence network. For a general description of said low-energy circuit, reference is again made to Figure 1, wherein a source of alternating current 33 is connected across reactor 40 by means of conductors 31 and 32. With such arrangement it is manifest that two shunt paths are available for receiving electrical energy from alternator 33, viz., (1) the reactor 40, and (2) the zero-phase sequence network. The latter path is described as consisting of neutral conductor 30 in series with the equivalent impedance of three parallel paths afforded by Y-connected transformer windings and transmission lines 11 in series with neutral conductor 60, the neutral windings 61 of special transformer 80, and the earth return to grounded terminal of reactor 40. Said latter path comprises the low-energy circuit referred to hereinbefore, since it is obvious that while current from alternator 33 passes through neutral winding 61 a voltage is induced in the equipment winding 62 because the latter winding is magnetically coupled to the former and is therefore a part of special transformer 80, hence by means of conductors 63 and 64 said voltage drives a current through a suitable load or energy receiver designated 65.

Practical usage of the low-energy circuit for achieving various conventional services will be described, together with certain paramount results which affect power-system equipment and operation. As an elementary example, a simple two-way signalling system affording audible-code communication between two remote stations along a transmission line, is illustrated schematically in Figure 3. For sake of clarity and comparison with Figure 1, a full-line diagram of the zero-phase sequence network is shown with said reactor 40 employed at one station and said special transformer containing neutral winding 51 and equipment winding 52 installed at the other station. Otherwise, both stations are equipped with identical terminal apparatus correspondingly designated. Local sources of single-phase alternating current employed for serving the signal system are represented by two bus-conductors designated 5, 6, and 5', 6' accordingly, which, for reasons of simplicity and economy may consist of the usual station lighting or power sources of fundamental frequency which are regularly available at all stations along a transmission line. Additional terminal apparatus at each station includes a single-pole double-throw switch 7 or 7', a simple relay 8 or 8', and a bell 9 or 9', which devices are arranged and interconnected schematically as depicted in Figure 3. Switches 7 and 7' are preferably of the return push-button variety in order that relays 8 and 8' may be normally connected for responding to incoming signals, as shown. Signals are transmitted by pressing said switches downward. For example, when switch 7 is so pressed, the circuit of relay 8 is first broken and then the zero-phase sequence network and reactor 40 are energized from local alternating-current source 5, 6, thus causing a current to flow in said network as previously described. At the opposite station this effects an induced voltage in equipment winding 52 and hence a current through coil of relay 8', which obviously actuates the armature of said relay and thereby the closure of the circuit of bell 9', causing said bell to be operated directly from its associated local source of alternating current 5', 6', as shown diagrammatically. Thus signals may be similarly transmitted from either station to the other, whereby said bell at one station is caused to operate in response to manipulations of said single-pole double-throw switch located at opposite station.

In view of the above disclosure, it is apparent that practically every kind of conventional low-energy service can be accomplished over the circuit by applying suitable auxiliary apparatus to the station reactors or equipment windings of special transformers depending upon which is employed, since as previously stated either is optional. However each utilization of a zero-phase sequence network requires prudent engineering. The network itself demands careful analysis; and then the impedance of the proposed low-energy circuit, minus reactors or special transformers, should be calculated or determined by actual test. At each station to be equipped with terminal apparatus for accomplishing the desired low-energy service, the following particulars are of utmost importance:

- (1) the magnitude of voltage to be introduced into the power system's neutral during the transmitting process,
- (2) range of non linear impedance to be presented by proposed reactor or neutral winding of special transformer,
- (3) maximum ground-fault current to be carried by pro-

posed reactor or neutral winding of special transformer, and (4) magnitude of normal neutral-current that flows continuously during regular operation of the power system. If the network includes many terminals or stations equipped with Y-connected grounded-neutral transformer banks, with some being unnecessary to the proposed low-energy service, then obviously the unnecessary stations actually constitute undesired shunt paths in which a portion of useful signal energy will be dissipated. In many instances said undesired shunt paths may be found so detrimental to efficient performance of the low-energy circuit that it will be necessary to increase their effective impedances to signal currents by the installation of suitable non linear reactors, wherein each of said reactors shall offer very low impedance to ground-fault currents and be capable of carrying safely the possible maximum of such fault current in accordance with previously disclosed principles.

Regarding the particulars of utmost importance as designated numerically in the preceding paragraph, the first, i. e., magnitude of voltage to be introduced into the power system's neutral during the transmitting process, is obviously of vital concern to safe operation of said power system. In general, it can be shown that the higher the operating voltage of the power transmission system the greater may be the magnitude of voltage that could be safely employed for transmitting current impulses in the low-energy circuit. Furthermore, a rigorous analysis of almost any given transmission system and its zero-phase sequence network will show that only a relatively low transmitting voltage—one that is considerably less than the maximum tolerable magnitude—will generally be sufficient to accomplish any conventional low-energy service. The slight additional stress imposed by said transmitting voltage on the insulation of Y-connected transformer windings and line conductors is of no practical significance. Likewise with reference to the relatively small circulating currents which flow in the delta-connected transformer windings while low-energy service currents pass through associated Y-connected windings. Moreover, said transmitting voltage produces no effect whatever on phase-to-phase voltages of either the high-or-low-voltage section of the power system, but obviously it does produce a comparatively small increase in one or more of the phase-to-ground voltages of the transmission equipment, with the particular phase increases being dependent upon the frequency of said transmitting voltage or its relative phase displacement when power-system frequency is employed.

The second particular of utmost importance as previously named, i. e., range of non linear impedance presented by the reactor or neutral winding of special transformer, is also of vital concern to satisfactory operation of the power system especially during ground-faulted conditions. As formerly disclosed in foregoing paragraphs, it is a primary requisite of our reactor and said neutral winding to present an unusually low impedance to passage of ground-fault current, chiefly for two reasons, viz., (a) so as to preclude an excessive neutral shift and phase distortion of transmission voltages with their harmful and often-times disastrous effects, and (b) for the economical purpose of avoiding additional capital investments in protective relay installations. Such a basis of design readily per-

mits universal application and satisfactory usage of our reactor and neutral winding of special transformer since they may be safely installed in series with other neutral devices customarily employed for various purposes by the industry, such as instrument current-transformers, neutral resistors, and Peterson tuning coils. Manifestly, to achieve this universal applicability and yet utilize said low-energy circuit with fair efficiency and high reliability, it is not only required that the magnetic circuit of said reactor or neutral winding saturate at a relatively low-magnitude of current of power-system frequency but also that the low-energy service itself be achieved by similar low-magnitude currents regardless of frequencies employed. These requirements invariably necessitate a range of non linear impedance to 60-cycle current which is practically identical to that formerly described with reference to Figure 2.

Regarding the third particular of utmost importance as previously named, i. e., maximum ground-fault current to be carried by reactor or neutral winding of special transformer, this matter has been formerly described as being the essential factor which determines the current-carrying capacity of our reactor or neutral winding of special transformer. Since neither said reactor nor neutral winding offers practically no impedance to passage of ground-fault current, by virtue of magnetic saturation and inherent non linearity of reactance suitably coordinated for reasons and purposes hereinbefore described, it is therefore self-evident that said reactor or neutral winding of special transformer must be capable of carrying safely the highest possible value of ground-fault current that could be experienced in the grounded neutral of the series-associated Y-connected transformer bank or banks which is utilized for the establishment of a terminal or station in the low-energy circuit. The same also applies to reactors installed in similar grounded neutrals at stations which are unnecessary to the low-energy service, yet constitute undesirable shunt paths as described in a former paragraph. But some economy can be realized in the selection of a suitable conductor for constructing the reactor or said neutral winding simply by taking advantage of the short time-duration of fault-current passage and the high thermal lag of an oil-immersed winding.

With reference to the fourth and last particular of utmost importance, i. e., magnitude of normal neutral current that flows continuously during regular operation of the power system, due recognition of this current must be given and in many instances means must be employed for preventing its interference with proper functioning of low-energy circuit apparatus. Various means may be used for rendering said normal current ineffective and of no consequence to receiving apparatus of the low-energy circuit, some of which are especially suited to certain kinds of low-energy services. For signalling and similar services achieved by intermittent impulses of current, interference from said normal current is readily prevented by the simple expedient of a receiving relay, such as those designated 8 and 8' in Figure 3. The small current flowing constantly through the coil of said relay as the result of normal neutral current is insufficient to operate the relay. And the magnitude of said small current is also well below the current magnitude at which the relay releases or drops out, consequently for all practical purposes said normal

neutral current is non-existent because the relay operates faithfully in response to current impulses received from a transmitting station. Obviously said current impulses received from a distant transmitting station are of a greater magnitude than the local normal neutral current, hence the magnitude of the latter current is important in determining an ample transmitting current to be employed at the distant station especially when the frequency of said transmitting current is the same as that of the power system.

A vacuum-tube receiving relay may be used instead of the electromagnetic relay previously described, especially when it is desired to operate the low-energy circuit at minimum signal strength. With a vacuum tube thus employed, interference from said normal neutral current is readily avoided by biasing the input grid circuit to plate-current cutoff so that only incoming signal voltages cause plate current to pass. Passage of plate current is then utilized in conjunction with suitable auxiliary apparatus as may be required for achieving the low-energy service.

In practicing our invention for the accomplishment of telephony as well as for services achieved by intermittent currents of frequencies higher than that of the power system, we utilize a high-pass electrical filter of conventional design solely for the purpose of avoiding interference from the normal neutral current. In such utilizations of a zero-phase sequence network the magnitude of signal current in a given terminal may be somewhat less than that of the normal neutral current, and yet the low-energy service may be effected in a satisfactory manner. Full disclosures of these elements of our invention are deferred to subsequent paragraphs for the sake of clarity and order of the specification.

Regardless of the particular low-energy service or combination of separate services accomplished over a zero-phase sequence network, we recognize the fact that safe and practicable installations dictate the employment of dependable and effective means for providing over-voltage protection to terminal apparatus of the low-energy circuit. Abnormally high voltages across said terminal apparatus result from lightning and switching surges as well as from ground faults on the power system. An over voltage caused by lightning or a switching surge actually exists over a relatively short time interval; it is generally characterized by damped waves of high frequencies, hence adequate protection against such an over voltage may be afforded by a suitable capacitor and conventional surge-suppressor type of resistor connected as hereinafter described. But an over voltage caused by a ground fault on the power system usually exists over a relatively longer time interval, which is necessitated by the operation of protective relays and circuit breaker involved in isolating the fault; it is a dynamic voltage of power-system frequency sustained by the power-system alternators and is therefore capable of rendering great damage to said terminal apparatus. Consequently, in view of the two distinctive classes of over voltages to which said terminal apparatus may be subjected, we include within the scope of our invention two distinctive over-voltage protectors wherein each of said protectors is designed to function in response to one of said distinctive classes of over voltages, that is, one protector responds to surge voltages caused by lightning and power-system switching operations and the other responds to

excessive dynamic voltages of fundamental frequency caused by power-system ground faults. Each protector is characterized by automatic service-restoring features in order that no manual attention or adjustments will be necessary for restoring service to the low-energy circuit after our protectors have operated.

Only one form of surge-voltage protector employed in combination with our reactor or special transformer and other associated devices hereinafter described is embodied within the scope of our invention, but several alternative forms of protectors designed to respond to excessive power-system voltages are likewise embodied as subsequently disclosed. One form of the latter protector is illustrated schematically in Figure 4, together with our surge-voltage protector and other associated devices as hereinafter described which are deemed absolutely essential to practical operation of terminal apparatus. For sake of clarity, the apparatus of only one station or terminal is shown in Figure 4 and is patterned after the elementary signal system previously discussed with reference to Figure 3, but it will be obvious that our over-voltage protectors and associated devices as hereinafter described shall function equally as well in conjunction with other kinds of low-energy circuit terminal apparatus. Our surge-voltage protector consists of a suitable capacitor 18 in combination with a conventional non linear resistor of the surge-suppressor type 19, with both of said devices being shunted across terminals of reactor 40, as shown. The theory of operation of said surge-voltage protector is well known and will not be herein described.

In Figure 4, local power-supply buses 5 and 6, bell 9, relay 8, and reactor 40 are identical to those of the elementary signal system formerly disclosed. The transmitting key 7, however, controls the coil circuit of relay 2 rather than making and breaking the transmitting current directly. Relay 2 is obviously of the conventional "break-in" type and when its armature is in the release position as shown it closes the low-energy circuit to both relay 3 and receiving relay 8. It will be observed that the coil of relay 1 is also connected across the circuit conductors like that of relays 3 and 8, so that incoming signals as well as over voltages are impressed across the coils of all three of said relays. The combination of relays 1 and 3 serves as protection against excessive voltages particularly those of power-system frequency; both relays have quick-operating characteristics and their minimum operating voltages are greater than the voltage of incoming signals so that only relay 8 responds to said incoming signals because its circuit continuity remains unbroken by the normally-closed contacts of relays 1 and 3. During signal transmission relays 3 and 8 are obviously disconnected from the circuit by relay 2, hence leaving relay 1 to be energized. But here also the minimum operating voltage of relay 1 is greater than the voltage of transmitted signals, thus relay 1 fails to respond to said transmitted signals and thereby maintains the circuit continuity through its normally closed contacts. Since the voltage of transmitted signals is greater than that of received signals, the minimum operating voltage of relay 1 is made slightly higher than that of transmitted signals, and the minimum operating voltage of relay 3 is made approximately equal to the maximum voltage permitted across coil of relay 8. Consequently if a ground fault occurs on the power system while a signal is being transmitted and if

the resultant voltage has sufficient magnitude, relay 1 will operate and thereby disconnect the local power supply so as to avert damage from excess voltage. But if such a fault occurs while relay 2 is in the release position and if the resultant voltage exceeds the maximum permissible voltage of relay 8, relay 3 will operate and thus disconnect the coil of relay 8; furthermore if the magnitude of said resultant voltage is sufficiently large to operate relay 1, the coil of relay 3 will be disconnected along with that of relay 8. Obviously for best coordination of protector relays 1 and 3, the minimum operating voltage of relay 1 should not exceed the maximum permissible voltage of relay 3 and the maximum permissible voltage of relay 1 should not be less than the highest voltage that is possible to experience from a ground fault on the power system. Because such perfect coordination is not always obtainable, our invention includes certain modifications of relays 1 and 3 which will be hereinafter described.

Other associated devices previously referred to as being essential to practical and efficient operation of low-energy circuit terminal apparatus consists of a fuse 15, Figure 4, a normally-open knife switch 16, and a suitable shunt-connected capacitor 17 which may also be series connected if preferred or when warranted as in installations of telephony or other services employing frequencies higher than the power-system frequency as will be hereinafter described. Said fuse obviously affords overall back-up protection, said knife switch provides a convenient means for bypassing reactor 40 when inspections or maintenance work on said reactor are to be performed, and said capacitor neutralizes partly at least the predominantly lagging inductive reactance of the low-energy circuit and is thereby highly beneficial to the operation of said circuit and its terminal apparatus during both transmission and reception of signals. Manifestly, in case our special transformer is used in lieu of reactor 40, said bypassing switch 16 and surge-voltage protector comprising capacitor 18 and resistor 19 are shunted across the neutral winding of said transformer, and the low-energy circuit conductors including fuse 15 leading to relay 1 are terminated on the equipment winding of said transformer.

Referring again to the coordination of voltage characteristics of protector relays 1 and 3 as previously discussed, said coordination is not always obtainable especially when there is considerable difference between the voltage of transmitted signals and the voltage of received signals. Either the maximum permissible voltage of relay 3 may be somewhat below the required minimum operating voltage of relay 1, or else the maximum permissible voltage of relay 1 may be somewhat below the highest possible voltage resulting from the maximum ground-fault current. In such instances it is obvious that either or both relays 1 and 3 may be supplemented with additional relays having appropriate voltage characteristics and likewise connected in cascade, however, said additional relays may be eliminated by utilizing relays of a special design in lieu of those of the ordinary variety as previously described and illustrated in Figure 4. Such a relay of special design is a form of the type having characteristics which are generally known as instantaneous operation and automatic time-delay release, the latter function being achieved by means of an auxiliary mechanism incorporated in the relay assembly. Among conventional designs of such a relay, an

air bellows, or a spring-or-electric-motor operated mechanism is usually employed for giving the automatic time-delay function which may be adjusted within certain limits for any desired time-interval. Such a relay may be used in place of either or both relays 1 and 3, and Figure 5 illustrates its electrical connections and mode of operation when substituted for relay 1. Said relay, when once operated by an over voltage, disconnects its own coil as well as other apparatus from the source of over voltage and then maintains this desired condition for a predetermined time-interval, irrespective of the duration of said over voltage, before the relay armature automatically releases and consequently re-establishes normal closed-circuited conditions. In Figure 5 only certain parts of said time-delay mechanism are illustrated schematically for conveying a general idea of how the relay functions. 21 and 22 are mechanical members constructed from electrical insulating materials, with the former associated with a pair of normally-closed contacts which may be operated in unison for opening the coil circuit, and with the latter member associated with both the relay armature and time-delay mechanism. Said members 21 and 22 are physically related in such manner that when the relay armature is actuated by the relay coil's magnetism, the low-energy circuit conductors are not only opened as in the ordinary relay previously described but the coil circuit is also opened by virtue of member 22 making mechanical contact with member 21 and thereby moving said latter member so as to break the coil-circuit contacts associated therewith. Simultaneously with these operations, the movement of the relay armature also initiates the time-delay mechanism, which may be one of various conventional types, so that when member 22 has driven member 21 sufficiently far to open the coil circuit as previously described the relay armature is mechanically latched in the operate or energized position and then held in said position for a predetermined period of time until released by said time-delay mechanism.

Our invention furthermore includes other certain alternative relays and auxiliary devices which may be advantageously employed as substitutes, not for the whole combination of previously designated protector relays 1 and 3 but only for relay 1 of said combination. One of such alternative relays is depicted in Figure 6, where relay 1 is operated directly by the fault current. The coil of said relay is joined in series with the reactor or neutral winding of special transformer, as indicated, so that the fault current must pass through said coil. This necessitates the coil to be wound of relatively large conductor, comparable with that contained in the reactor or neutral winding of special transformer, but no difficulty is presented when the relay coil and reactor or said neutral winding are thus employed in series combination at a station where the maximum ground-fault current is relatively small. In a special transformer installation, it is obvious that the low-energy circuit conductors including fuse 15 would lead from the equipment-winding terminals of said transformer, but otherwise the connections to contacts of relay 1 would be made as shown in Figure 6. With such a series arrangement of relay 1, a wide range of coordination with relay 3 is made available. Relay 1 is simply adjusted to operate at a value of current which gives a voltage that does not exceed the maximum permissible voltage of relay 3.

Another alternative relay in combination with

an instrument current-transformer is depicted in Figure 7. As illustrated schematically, the primary winding of said instrument current-transformer 23 is joined in series with the reactor or neutral winding of special transformer, and the secondary winding of said transformer is electrically connected to the coil of relay 1. Said relay is therefore operated by a current which bears a definite ratio to the fault current, which ratio is obviously fixed by the current-transformer. Consequently, the current-transformer ratio and minimum current required to operate relay 1 may be coordinated in a manner that permits said relay to operate when the value of fault current equals or exceeds that value which gives a voltage not in excess of the maximum permissible voltage of relay 3.

Still another alternative relay in combination with other devices and equipment is shown schematically in Figure 8, wherein our special transformer is utilized in lieu of the reactor merely for the purpose of illustrating the interchangeability of said devices as previously described. In this modification, relay 1 is a quick-acting heavy-duty magnetic contactor with normally-open contacts connected for short-circuiting the neutral winding or reactor, as shown. It is preferably a direct-current operated type, hence its coil is energized by the operation of an auxiliary relay 24 through conductors 25 and 26 which lead from a source of direct-current supply not shown. Obviously the coil of relay 24 is energized from the secondary winding of instrument current-transformer 23, so that the operation of said relay and subsequent operation of relay 1 are controlled by the magnitude of current flowing in the primary winding of said current transformer, thereby providing a practical means for coordinating the operation of said relay 1 with the maximum permissible voltage of relay 3 in accordance with aforesaid reasons and purposes. In this arrangement relays 2 and 3 retain their original relationship as shown in the diagram, with the low-energy circuit conductors and fuse 15 being terminated on the equipment winding or obviously across the reactor when the latter is substituted for a special transformer.

To utilize the low-energy circuit for telephonic communication, we employ in combination with previously described apparatus a conventional vacuum-tube speech amplifier for signal transmission, and a similar but smaller amplifier associated with an electrical filter for signal reception. Said devices and their electrical connections are illustrated schematically in Figure 9, including all terminal apparatus required at one station except our reactor or special transformer and protector relay 1, it being understood that the reactor and special transformer are optional devices and that relay 1 can be one of several alternative forms according to previous disclosures. Low-energy circuit conductors which lead from said optional equipment connect to the armature contacts of break-in relay 2, as in installations formerly described. Protector relay 3 is also employed in the same manner as previously explained, however, its use is generally unnecessary since the electrical filter hereinafter described affords considerable protection against over voltages of power-system frequency. From buses 5 and 6 is supplied the electrical energy necessary for the operation of said amplifiers and relay 2. Push-button switch 43 is normally open so as to maintain the armature of relay 2 in its release position, as shown. Circuit continuity for

incoming speech-signals is thus established through normally-closed contacts of relay 3, through electrical filter 46, through amplifier 47, and into receiver or loud speaker 48. Said electrical filter is a conventional design of the high-pass variety, but constructed for a sharp cut-off in the region of 200 cycles so as to greatly attenuate all frequencies below 200 cycles and pass without distortion or excessive energy loss all frequencies above said cut-off region. Its use prevents a constant noise disturbance in said receiver or loud speaker which, otherwise, would result from the normal residual or neutral current previously described. Since the predominant frequencies of said normal neutral-current are the fundamental and its third harmonic, which in the common 60-cycle power system are 60 cycles and 180 cycles respectively, passage of these frequencies through the amplifier and into said receiver or loud speaker is thus prevented by said filter without impairing the quality of speech, because an excellent quality of telephony may be had in a frequency band extending from a minimum of 250 cycles per second to a maximum of approximately 2,750 cycles per second. Within this frequency band obviously lies other harmonics of the triple-frequency group such as the 9th, 15th, and higher odd multiples contained in the aforesaid normal neutral current, to which said filter is ineffective. However, the relative voltage-amplitudes resulting from said latter harmonic currents are indeed very low, so low in fact that noise disturbances from them are readily averted by employing a higher voltage-amplitude of incoming speech signals. That is, the ratio of signal voltage to effective voltage of said latter harmonic frequencies is made high enough to avoid a constant noise disturbance. Amplifier 47 is utilized principally as a power amplifier, with its input circuit serving for the terminating loading-resistance of said filter 46.

With further reference to Figure 9, transmission of voice signals is achieved by first depressing switch 43 and then speaking into microphone 44 while retaining said switch in the depressed position throughout the interval of transmission. Manifestly, the former operation actuates relay 2, thereby disconnecting said receiving apparatus and then connecting the transmitting speech-amplifier 45 to the low-energy circuit. Minute voice currents from said microphone are enlarged to a suitable power level by said amplifier and hence fed directly into the low-energy circuit in the same manner as other signal currents formerly described. To obtain efficient performance, a series-connected capacitor 47 of suitable ratings is employed for neutralizing the positive reactance of said low-energy circuit. Further improvements are also effected by matching the impedance of the output element of said amplifier 45 with that of the low-energy circuit.

In Figure 10 we illustrate schematically an example of how two separate low-energy services may be achieved independently and simultaneously without mutual interference over the single physical circuit afforded by a zero-phase sequence network. As will be manifested in subsequent disclosures, a greater number of said services may be likewise achieved but only two are illustrated for sake of clarity. The basic means and methods employed are well known, yet the novelty of our invention lies in the particular manner of adapting said means and methods for practical usage in combination with certain of our aforesaid devices. A definite frequency-

channel is assigned to each individual service, and while Figure 10 depicts terminal apparatus of two of said channels installed at a given station it must be understood that in actual practice the terminal apparatus of one channel may be located at one station and that of the other channel located at still another station. In a rather extensive zero-phase sequence network—one having a large number of terminals or stations remotely located from each other—it is therefore practicable to establish one or more channels between certain stations and still other channels between other stations, so as to enable several low-energy services to be accomplished over the common circuit as though a separate physical circuit existed for each of said services between the particular stations involved. Consequently a given power-transmission system may be so equipped that practically all essential installations of telemetering, remote automatic supervisory control of vital functions and equipment, as well as communication requirements between generating plants and important substations, may be accomplished in a reliable manner with considerable economy.

In utilizing successive impulses of alternating current for the achievement of aforesaid services, it will be obvious that each service can be had by employing both transmitting and receiving apparatus which functions only with currents of a predetermined frequency, whereby the transmitting apparatus injects impulsive currents of said predetermined frequency into the physical circuit and the corresponding receiving apparatus located at one or more distant stations responds only to currents of the same predetermined frequency. Said predetermined frequency with its correlated transmitting and receiving apparatus is therefore regarded as a channel superimposed on the physical circuit, and manifestly its use permits the achievement of a single low-energy service. It is clear that said service may be of the "one-way" type necessitating current transmission at only one station and reception at one or more other stations, or it may be of the "two-way" type requiring both transmission and reception at each station involved. For either type of service, the aforesaid terminal apparatus is necessarily employed in combination with our reactor or special transformer and other associated devices formerly described as being essential to a practical installation. However, in Figure 10 our reactor or special transformer, surge-voltage protector and bypassing switch are omitted for obvious reasons just as in certain foregoing illustrations. Furthermore, even though we depict one form of our protector relay 1, it is understood that other alternative forms of said relay as previously shown and described may be substituted according to prevailing conditions and preferences of the designer without departing from the scope of our invention. It is also significant that our protector relay 3 hereinbefore illustrated and described as an essential device operatively-coordinated with protector relay 1 in other simpler installations of terminal apparatus, does not appear in the diagram. Whether or not said relay 3 can be likewise employed in an installation of aforesaid frequency-channel terminal apparatus depends not only on the relative magnitudes of transmitted and received currents but also on the actual frequencies of said currents. However, its need in such installations usually will not exist, owing to the protective characteristics of the electrical filters

employed therein and subsequently described. Therefore an alternative form of relay 1 as shown will in almost all installations afford sufficient protection against overvoltages of power-system frequency.

The frequency-channel terminal apparatus illustrated in Figure 10 is merely representative of such apparatus as would ordinarily be required for any two-way low-energy service excepting telephony. Separate transmitting and receiving devices for each of aforesaid channels are shown for the purpose of simplifying the description of operation, although it must be understood that with certain kinds of services especially printer telegraphy or teletype communication service the functions of transmission and reception are jointly performed by use of a single instrument. This difference, however, does not indicate a departure from basic principles but is simply a matter of detail, since all installations regardless of particular services achieved make use of certain equipment in common, viz., a source of alternating current of a prescribed frequency for supplying the energy of transmitted signals or impulsive currents, and an electrical filter or its equivalent in the form of a mechanically-tuned frequency-responsive relay for assuring proper reception of incoming signals. Thus, in Figure 10 there is electrically associated with each transmitting key or switch 75 and 85 a source of alternating current of a given frequency, designated 76 and 86 respectively. The frequencies of said sources are fixed by conventional vacuum-tube oscillators or suitable electric-motor driven alternators electrically supplied from local buses 5 and 6, and having a frequency difference sufficient to insure positive operation of receiving devices of the respective channels. Said difference depends largely upon the characteristics of electrical filters 77 and 87, each of which is a form of the conventional band-pass filter whose midfrequency is manifestly equal to the operating frequency of the particular channel. Receivers 78 and 88 may be of any customary design suited to their respective services; but each is necessarily equipped with a suitable electromagnetic, or vacuum-tube, relay adapted to respond to impulsive currents of the particular frequency which is allowed passage through the electrical filter associated therewith. The functions of break-in relays 2 and 2', and capacitors 17 and 17', are obvious from foregoing descriptions.

Further consideration will show that it is practicable to effect a combination of frequency-channel apparatus and voice communication, meaning that the terminal apparatus depicted in Figure 10 can be combined with that shown in Figure 9. In which case, most of the channel frequencies would necessarily be above an arbitrarily selected frequency which would represent the highest useful speech frequency, say 2,500 cycles per second. It would also be desirable and perhaps essential to utilize a suitable electrical filter in conjunction with transmitting amplifier 45 and break-in relay 2 of Figure 9, so as to prevent the transmission of audible frequencies above the said arbitrarily selected frequency. Moreover, a band-pass filter passing frequencies between a minimum of about 250 and the said arbitrarily selected maximum frequency, must be substituted for the high-pass filter 46 of Figure 10 in order to avert disturbing noises from the channel frequencies. But the frequency-channel apparatus would, in principle, remain as described with reference to Figure 10.

Inasmuch as many changes may be made in the systems shown on the accompanying drawings, without departing from the spirit and scope of our invention, we do not desire to be limited in scope except as may be indicated in the appended claims.

We claim as our invention:

1. A system for utilizing the zero-phase sequence network of a multiple grounded-neutral electric power transmission system which includes, means for connecting a source of alternating current between the ground and neutral of said power transmission system, a conducting element of adequate current-carrying capacity which inherently possesses a nonlinear impedance characteristic of a suitable range to currents of power-system frequency and which is permanently connected in series between the ground and neutral of said power transmission system, and signal receiving means responsive to alternating currents and electrically connected between the ground and neutral of said power transmission system, whereby the ground-return circuit afforded by said zero-phase sequence network is employed for rendering conventional low-energy electrical services such as remote metering, supervisory control, and intelligence communication at a plurality of substations distantly located along said power transmission system without jeopardizing the safety of our interfering with the usual and regular performance of said power transmission system when operating either normally or under ground-faulted conditions.

2. In combination with a multiple grounded-neutral electric power transmission system of, a conducting element of adequate current-carrying capacity which inherently possesses a nonlinear impedance characteristic of a suitable range to currents of power system frequency and which is permanently connected in series between the ground and neutral of said power transmission system at each of a plurality of substations therealong, and means electrically associated with said conducting element at each of said plurality of substations for transmitting and/or receiving alternating current impulses or signals, whereby electric signalling between said plurality of substations is accomplished and the said power transmission system with all its main and auxiliary equipment is allowed to operate under ground-faulted conditions in practically the same usual and regular manner as originally provided for and/or experienced.

3. The method of signaling over a multiple grounded-neutral electric power transmission system which consists in, employing a conducting element of adequate current-carrying capacity which inherently possesses a nonlinear impedance characteristic of a suitable range to currents of power-system frequency and which is permanently connected in series between the ground and neutral of said power transmission system at each of a plurality of substations distantly located along said power transmission system, transmitting alternating current impulses or signals at one of said substations and receiving said impulses or signals at the remaining of said substations, whereby electric signaling between said plurality of substations is accomplished without jeopardizing the safety of or interfering with the usual and regular performance of said power transmission system when operating either normally or under ground-faulted conditions.

4. Apparatus for signaling over the ground-return circuit afforded by a zero-phase sequence network of an electric power transmission system which includes, a conducting element of adequate current-carrying capacity which inherently possesses a non-linear impedance characteristic of a suitable range to currents of power system frequency and which is permanently connected in series between the ground and neutral of the power transmission system at each of a plurality of substations distantly located along said power transmission system, means for transmitting and/or receiving alternating current impulses or signals associated with said non-linear impedance element at each of said plurality of substations, whereby electric signaling between said substations is accomplished without jeopardizing the safety of or interfering with the usual and regular performance of said power transmission system when operating either normally or under ground-faulted conditions.

5. A linked electrical circuit consisting essentially of three links with two of said links comprising local circuits remotely located from each other but electrically coupled to and joined by a long distance intermediate link, each of said local circuits containing means for transmitting and/or receiving alternating current impulses or signals and is located at a substation along a power transmission system, said long distance intermediate link being a ground-return circuit which includes the transmission line conductors of a power transmission system which terminate in grounded-neutral Y-connected power transformer banks remotely located from each other at different substations along said power transmission system where said local circuits are also located, and an electrical coupling device permanently joined in series between the ground and neutral of said Y-connected power transformer bank at each of said different substations along said power transmission system, with each of said electrical coupling devices inherently possessing a nonlinear impedance characteristic of a suitable range to currents of power-system frequency and having adequate current-carrying capacity for safely conducting the maximum ground-fault current permissible through its adjacently series-connected grounded-neutral power transformer bank, whereby alternating current impulses or signals transmitted at one of said substations are received at the opposite substation by virtue of said intermediate link which is provided by the zero-phase sequence network of said power transmission system.

6. A system for signaling over the ground-return circuit afforded by a zero-phase sequence network which includes at a substation which is unnecessary to the signaling system and which therefore constitutes an undesired shunt path in said ground-return circuit, the installation and use of a conducting element of adequate current-carrying capacity which inherently possesses a nonlinear impedance characteristic of a suitable range to currents of power-system frequency and which is permanently connected in series between the ground and neutral of the power transmission system at said unnecessary substation, whereby the dissipation of useful signal energy is greatly decreased, and the power transmission system with all its main and auxiliary equipment is allowed to operate under ground-faulted conditions in practically the same usual and regular manner as originally provided

for and/or experienced prior to the installation of said conducting element.

7. A system for signaling over the ground-return circuit afforded by a zero-phase sequence network including, a nonlinear impedance element as previously set forth, means for transmitting alternating current impulses or signals, means for receiving alternating current impulses or signals, and means for preventing the normal residual or neutral current from electrically interfering with said receiving means, wherein said normal residual or neutral current flows constantly through said nonlinear impedance element during normal and regular operation of the power transmission system, and correct performance of said receiving means is accomplished.

8. A system for signaling over the ground-return circuit afforded by a zero-phase sequence network including, a nonlinear impedance element as previously set forth, means for transmitting alternating current impulses or signals, means for receiving alternating current impulses or signals, means for preventing the normal residual or neutral current from electrically interfering with said receiving means, and means for neutralizing the inductive reactance of said ground-return circuit, whereby more efficient performance of said circuit and associated terminal apparatus is accomplished.

9. A system for signaling over the ground-return circuit afforded by a zero-phase sequence network including, a nonlinear impedance element as previously set forth, means for transmitting alternating current impulses or signals, means for receiving alternating current impulses or signals, means for preventing the normal residual or neutral current from interfering with said receiving means, means for neutralizing the inductive reactance of said ground-return circuit, and means for quickly disconnecting said receiving means from and similarly connecting said transmitting means to said ground-return circuit and, conversely, disconnecting the said transmitting means upon cessation of signal transmission and then reconnecting the said receiving means, whereby electrical switching of both transmitting and receiving means to and/or from said ground-return circuit is facilitated and accomplished.

10. A system for signaling over the ground-return circuit afforded by a zero-phase sequence network including, a nonlinear impedance element as previously set forth, means for transmitting alternating current impulses or signals, means for receiving alternating current impulses or signals, means for preventing the normal residual or neutral current from electrically interfering with said receiving means, means for neutralizing the inductive reactance of said ground-return circuit, means for switching both the transmitting and receiving means to and/or from said ground-return circuit, and means for protecting both said transmitting and receiving means against excessive surge voltages caused by lightning and power system switching operations.

11. A system for signaling over the ground-return circuit afforded by a zero-phase sequence network including, a nonlinear impedance element as previously set forth, means for transmitting alternating current impulses or signals, means for receiving alternating current impulses or signals, means for preventing the normal residual or neutral current from electrically interfering with said receiving means, means for

switching both said transmitting and receiving means to and/or from said ground-return circuit, means for protecting both said transmitting and receiving means against excessive surge voltages caused by lightning and power system switching operations, and means for protecting both said transmitting and receiving means against excessive dynamic voltages of power-system frequency resulting from ground faults on the power transmission system.

12. A system for signaling over the ground-return circuit afforded by a zero-phase sequence network including, a non-linear impedance element as previously set forth, means for transmitting alternating current impulses or signals, means for receiving alternating current impulses or signals, means for preventing the normal residual or neutral current from electrically interfering with said receiving means, means for switching both said transmitting and receiving means to and/or from said ground-return circuit, means for protecting both said transmitting and receiving means against excessive surge voltages caused by lightning and power system switching operations, means for protecting both said transmitting and receiving means against excessive dynamic voltages of power system frequency resulting from ground faults on the power transmission system, and means for electrically bypassing said nonlinear impedance element.

13. In combination with the zero-phase sequence network of an electric power transmission system of, a plurality of conducting elements having adequate current-carrying capacities and inherently possessing non linear impedance characteristics of suitable ranges to currents of power system frequency, means for transmitting alternating current impulses or signals, means for receiving alternating current impulses or signals, means for preventing electrical interference from the normal residual or neutral current which flows constantly during normal and regular operation of said power transmission system, and means for electrically bypassing each of said plurality of conducting elements.

14. In combination with the zero-phase sequence network of an electric power transmission system of, a plurality of conducting elements having adequate current-carrying capacities and inherently possessing nonlinear impedance characteristics of suitable ranges to currents of power system frequency, means for transmitting alternating current impulses or signals, means for receiving alternating current impulses or signals, and means for neutralizing the inductive reactance of the ground-return circuit afforded by said zero-phase sequence network.

15. In combination with the zero-phase sequence network of an electric power transmission system of, a plurality of conducting elements having adequate current-carrying capacities and inherently possessing nonlinear impedance characteristics of suitable ranges to currents of power system frequency, means for transmitting alternating current impulses or signals, means for receiving alternating current impulses or signals, means for switching both said transmitting and receiving means to and/or from said zero-phase sequence network, and means for protecting both transmitting and receiving means against excessive over voltages arising from transient surges and/or ground faults on said electric power transmission system.

16. The method of telegraphing over the

ground-return circuit afforded by the zero-phase sequence network of a power transmission system which consists in, employing a conducting element of adequate current-carrying capacity which inherently possesses a nonlinear impedance characteristic of a suitable range to currents of power system frequency and which is permanently connected in series between the ground and neutral of said power transmission system at each of a plurality of substations distantly located along said power transmission system, transmitting telegraphic code impulses of alternating current at one of said substations and receiving said telegraphic code impulses at the remainder of said substations, whereby communication of intelligence between said plurality of substations is accomplished without jeopardizing the safety of or interfering with the usual and regular performance of said power transmission system when operating either normally or under transient-faulted conditions.

17. In combination with the ground-return circuit afforded by the zero-phase sequence network of a power transmission system of, a conducting element of adequate current-carrying capacity which inherently possesses a nonlinear impedance characteristic of a suitable range to currents of power system frequency and which is permanently connected in series between the ground and neutral of said power transmission system at each of a plurality of substations therealong, and means electrically associated with said conducting element at each of said plurality of substations for transmitting and receiving voice or speech signals, whereby telephonic communication is achieved over the said ground-return circuit.

18. The method of telephoning over the ground-return circuit afforded by the zero-phase sequence network of a power transmission system which consists in, employing a conducting element of adequate current-carrying capacity which inherently possesses a nonlinear impedance characteristic of a suitable range to currents of power system frequency and which is permanently connected in series between the ground and neutral of said power transmission system at each of a plurality of substations distantly located along said power transmission system, transmitting voice or speech signals at one of said substations and receiving said voice or speech signals at the remainder of said substations, whereby communication of intelligence between said plurality of substations is accomplished without jeopardizing the safety of or interfering with the usual and regular performance of said power transmission system when operating either normally or under ground-faulted conditions.

19. In combination with the ground-return circuit afforded by the zero-phase sequence network of a power transmission system of, a conducting element of adequate current-carrying capacity which inherently possesses a nonlinear impedance characteristic of a suitable range to currents of power system frequency and which is permanently connected in series between the ground and neutral of said power transmission system at each of a plurality of substations therealong, and means electrically associated with said conducting element at each of said plurality of substations for superimposing a plurality of separate and distinct carrier-frequency channels on the said ground-return circuit, whereby a plu-

5 rality of separate and distinct services as rendered by successive impulses of alternating currents are achieved simultaneously over said ground return circuit without mutual interference among said channels.

- 10 20. The method of superimposing a plurality of separate and distinct carrier-frequency channels on the ground-return circuit afforded by the zero-phase sequence network of a power transmission system which consists in, employing a conducting element of adequate current-carrying capacity which inherently possesses a non-linear impedance characteristic of a suitable range to currents of power system frequency and
- 15 which is permanently connected in series between the ground and neutral of said power transmission system at each of a plurality of substations

distantly located along said power transmission system, transmitting a plurality of carrier-frequency alternating currents or impulses at one or more of said substations and receiving said plurality of carrier-frequency alternating currents or impulses at the remainder of said substations, whereby a plurality of separate and distinct conventional low-energy electrical services are achieved simultaneously without mutual interference over said ground-return circuit, and the power transmission system with all its main and auxiliary equipment is allowed to operate under ground-faulted conditions in practically the same usual and regular manner as originally provided for and/or experienced.

JEWEL D. BROWDER.
DONALD C. HARDER.