March 8, 1938. A. J. McCONNELL 2,110,673

ELECTRORESPONSIVE DEVICE

Filed Nov. 21, 1936 2 Sheets-Sheet 1

Fig. 1.

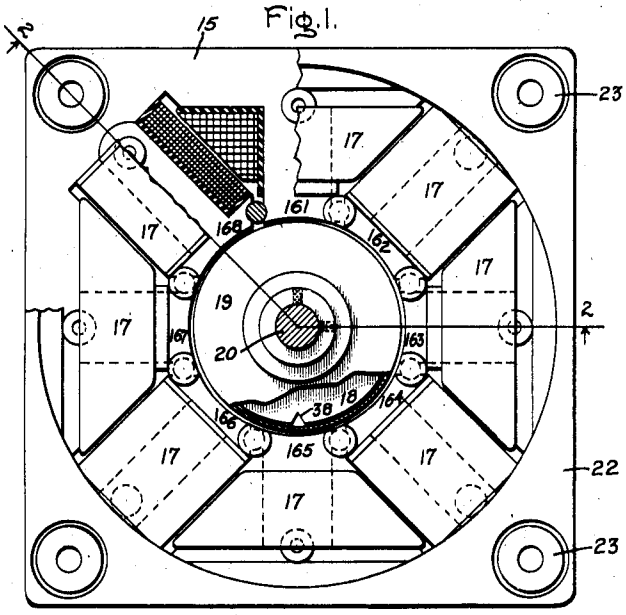


Fig. 3.

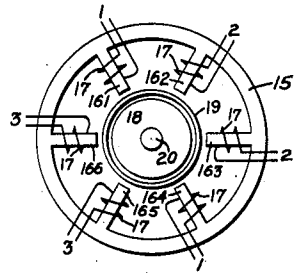


Fig. 4.

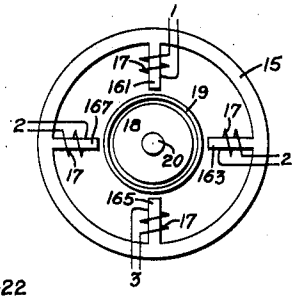


Fig. 2.

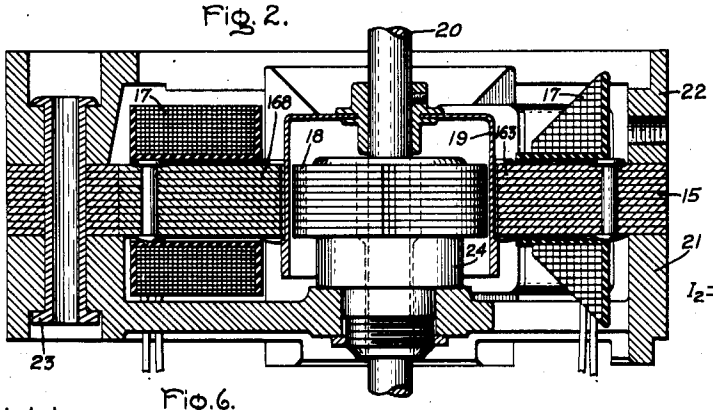


Fig. 5.

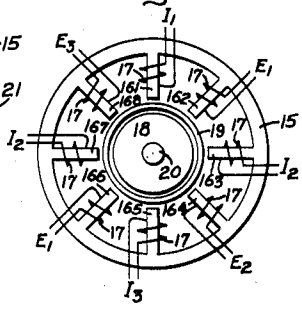
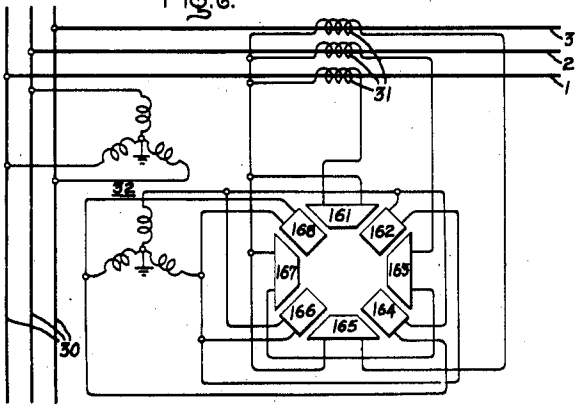


Fig. 6.



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ELECTRORESPONSIVE DEVICE

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Fig. 7.

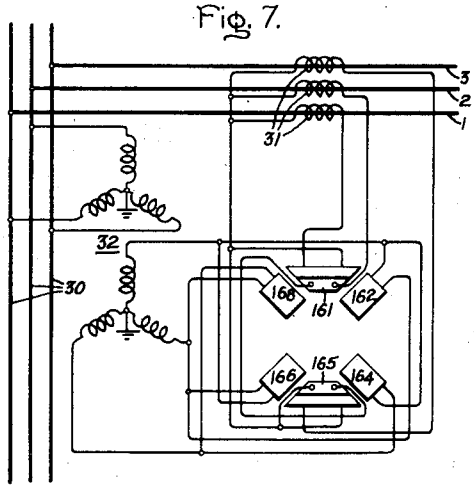


Fig. 8.

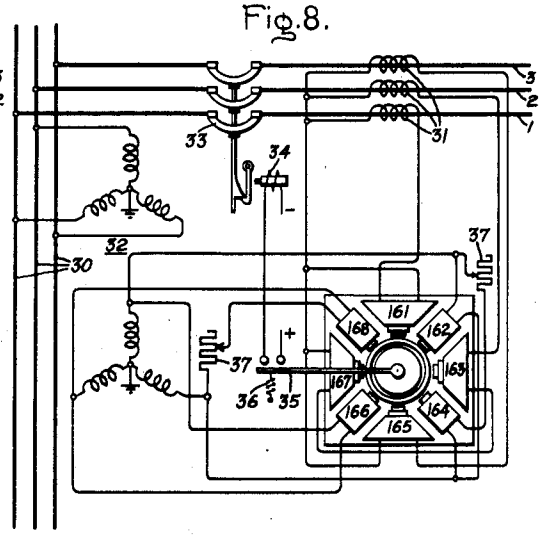


Fig. 9.

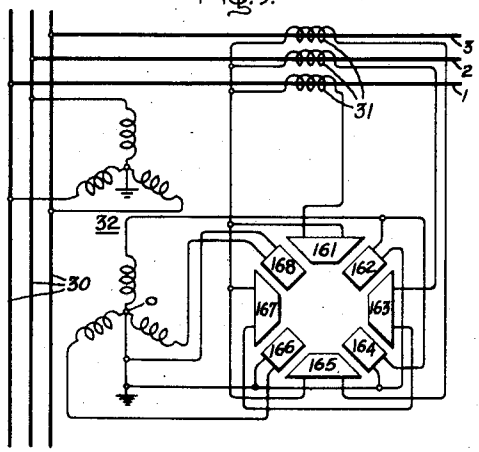


Fig. 10.

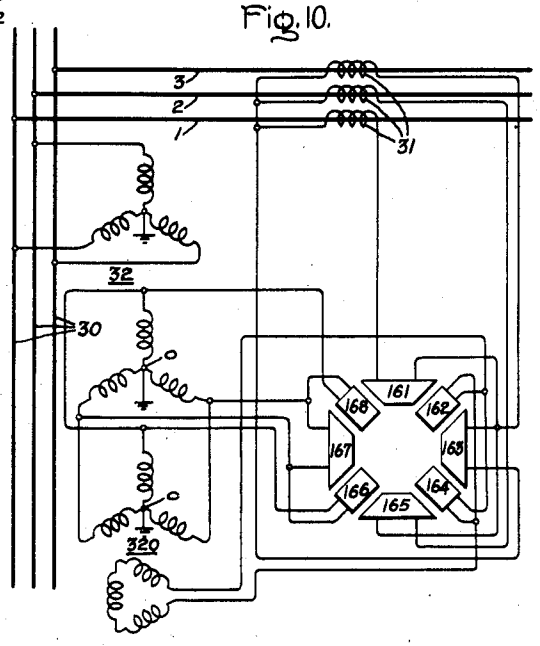
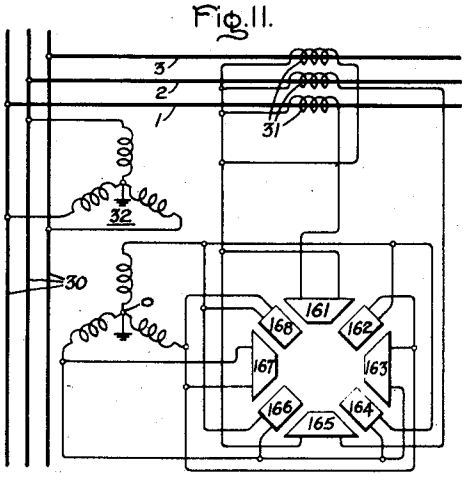


Fig. 11.



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Patented Mar. 8, 1938 2,110,673

UNITED STATES PATENT OFFICE

2,110,673

ELECTRORESPONSIVE DEVICE

Andrew J. McConnell, Upper Darby, Pa., assignor to General Electric Company, a corporation of New York

Application November 21, 1936, Serial No. 112,068

14 Claims. (Cl. 175—294)

My invention relates to improvements in electroresponsive devices and more particularly to improvements in protective relays for polyphase alternating current systems. In general, my invention relates to improvements in electroresponsive devices such as are disclosed and claimed in the copending application of D. C. Prince, Serial No. 112,067, filed November 21, 1936, for Electroresponsive device, and assigned to the same assignee as this invention. An object of my invention is to provide an improved multiple purpose electroresponsive device for polyphase circuits.

In the manufacture of polyphase wattmetric devices such as wattmeters and polyphase power directional relays, it has been customary to use two or more electric current conducting rotors such as disks, for example, on a single shaft with one or more separate electromagnetic means on each rotor for producing a torque thereon. Such devices, because of their size, require a relatively large space and switchboard area. Also, since they have a low efficiency and high inertia, they do not meet present day relay requirements for high torque and speed. Moreover, when in connection with a polyphase power directional relay it is desired to use voltage restraint, as disclosed in United States Letters Patent 1,883,839, of R. L. Webb, the construction becomes further involved by the addition of another electromagnetic torque producing means. Also, where both phase and ground fault protection involve the use of power directional relays, it has been customary to provide at least two entirely separate and distinct power directional relays, one a polyphase power directional relay for phase faults and one a ground directional relay for ground faults.

In accordance with my invention, I provide an improved multiple purpose electroresponsive device which is compact and simple in construction and which provides a high torque and fast operation. Also in accordance with my invention, I provide an electroresponsive device in which, with only one electric current conducting rotor, a polyphase power directional response can be obtained either with or without voltage restraint and which may also include a ground power directional response. Further in accordance with my invention, I provide an improved means for eliminating certain undesirable torque effects whereby to improve the accuracy of the response of a polyphase device having a single electric current conducting rotor. These and other objects of my invention will be better understood from the following description when considered in connection with the accompanying two sheets of drawings, and its scope will be pointed out in the appended claims.

In the accompanying drawings, Fig. 1 is a plan view of an electroresponsive device construction adapted to the carrying out of my invention; Fig. 2 is a sectional elevation on the line 2—2 of Fig. 1 as seen in a vertical plane after revolution of the diagonal portion of the section; Figs. 3, 4, and 5 are schematic views of devices similar to that shown in Figs. 1 and 2 and are presented for explanatory purposes; Fig. 6 is a diagrammatic view illustrating schematically an electroresponsive device, such as shown in Figs. 1 and 2, connected in a polyphase circuit for directional response to the polyphase power of the circuit; Figs. 7–11 are diagrammatic views illustrating various modifications of my invention.

The electroresponsive device illustrated in Figs. 1 and 2 is similar in construction to the electroresponsive device disclosed in the copending application of V. E. Verrall, Serial No. 70,580, filed March 24, 1936, for Electroresponsive devices. As shown in Figs. 1 and 2, this device comprises a hollow magnetic stator 15 having a plurality of inwardly projecting salients 161–166, inclusive. Certain of these salients, those on the sides, for example, may be integral with the stator and the others insertable in the stator. Windings 17 are provided for energizing the salients and also a central magnetic member 18, concentrically positioned with respect to the ends of the salients, whereby to actuate a rotor 19 which is movable in the gaps between the salients and the stator 18, the rotor being secured to a suitably journaled shaft 20. The parts described are assembled as a unit between two end frames 21 and 22, which are held together by suitable means such as rivets 23. For reasons which will hereinafter appear and as disclosed in the copending application of E. H. Bancker, Serial No. 112,069, filed November 21, 1936, for Electroresponsive devices, one of the end frames, for example, the frame 21 which supports the stator 18, is preferably of magnetic material, as is also the supporting member or hub 24 on which the central magnetic member is mounted.

In Figs. 3, 4, and 5, which are intended as schematic representations of devices analogous to that shown in Figs. 1 and 2, similar reference numbers indicate corresponding parts. In the Prince application referred to herein, it is shown that if the windings 17 on a device having six salients 161—166, inclusive, are energized by a set of three-phase quantities 1, 2, 3, in the order

1,2, 2,1, 3,3, as indicated by the numbers at the ends of the respective windings **17**, then the rotating field poduced by the windings on the salients **161**, **163**, **165** is opposite in torque effect to the rotating field produced by the windings **17** on the salients **162**, **164**, **166**. Other things being equal, the resultant torque on the rotor **19** is zero. Also as disclosed in the Prince application, this same action can be obtained with a simplified stator **15** having only four salients for a three-phase system of electric quantities, as shown in Fig. 4, or in general $2(n-1)$ salients for an n-phase system. Thus, if the windings **17** are energized by three phase quantities, as for example, the phase currents of a three-phase system in the cyclic order 1,2, 3,2, as indicated by the numbers at the ends of the respective windings, then the direction of the rotating field produced by the windings **17** on the salients **161**, **163**, **165** is opposite to the direction of the rotating field produced by the salients **161**, **167**, **165**. Other things being equal, the resultant torque is zero and the rotor **19** is not actuated. The windings **17** may be energized by a set of three-phase voltages in a similar order, and the resultant torque on the rotor would be nothing.

If, however, it is desired to obtain a torque which is dependent, for example, on the sum of the products of the currents and the voltages of a polyphase system and have such torque independent of terms of the second order involving only current or voltage, then, as pointed out in the Prince application, alternate salients may be energized by the currents in the three phase conductors of a three-phase system in the cyclic order I_1, I_2, I_3, I_2, for example, and the windings **17** on the intermediate salients by three phase voltages of the system in the order E_1, E_2, E_1, E_3. In this way, the resultant torque is proportional to $\Sigma EI \cos(\phi+\theta)$, where E and I represent respectively the currents and the voltages of the circuits, ϕ the angle at which the current lags the voltage in the system, and θ the angle of lead (current leading voltage) at which maximum torque occurs.

In order more clearly to illustrate this torque feature in its application to a three phase circuit, I have shown schematically in Fig. 6, the connection of the windings of the device shown in Figs. 1 and 2 in a three-phase system. As illustrated, the three-phase system comprises a three-phase circuit whose phase conductors, designated 1, 2, 3 for simplicity in phase order, may constitute a feeder extending from a station bus **30**. The respective phase currents may be derived through current transformers **31** connected in the phase conductors and the voltages through a potential transformer **32** connected to the bus **30**. In this figure, the current energized windings are shown on the vertical and horizontal salients with reference to Fig. 1, and the voltage energized windings on the diagonal salients with reference to Fig. 1. Only the windings are shown in this figure and for simplicity they will be designated by the corresponding numbers of their salients. The salients **161**, **163**, **165**, **167**, are energized by the phase currents I_1, I_2, I_3, I_2, respectively, so that the resultant torque on the rotor, not shown, of the windings on these salients is zero except for possible discrepancies due to manufacturing limitations or tolerances. In other words, there are no second order terms involving the products of two currents to introduce an error in a desired voltage-current product function. The salients **162**, **164**, **166**, **168** are energized in accordance with the phase voltages E_{23}, $-E_{12}$, $-E_{23}$, and E_{31}, respectively. The resultant torque on the rotor of the windings on these salients is accordingly zero. In other words, there are no second order terms involving the products of two voltages to introduce an error into the desired function of current voltage products, all as disclosed in the Prince application referred to. It has been found that these second order terms alone may introduce such an appreciable torque as to render a relay device unreliable for protective purposes unless such second order terms can be eliminated. Thus for example, these second order terms may amount to 15% of the actual power directional torque to which the device is supposed to respond.

There may be occasions, however, when it is desired to obtain a torque balance for one of the groups of polyphase quantities and to have a predetermined bias or restraint effect derived from some other source, such, for example, as the other group of polyphase quantities. In this case, it is desirable that vacant salients, on which suitably energized windings may be placed to obtain the desired effect, be available. In order to accomplish the torque balance feature and yet to have the available structure for a predetermined restraint characteristic, I may arrange, in accordance with my invention as shown in Fig. 7, to have two diametrically opposite salients **161** and **165** energized, for example, by the current differences (I_1-I_2) and (I_2-I_3), respectively. In this way, there will be no second order term involving currents alone. The salients **162**, **164**, **166**, and **168** may have their windings energized respectively by the voltages E_{23}, E_{12}, E_{23}, and E_{31}, and these will of themselves produce no torque on the rotor. The resultant torque of the salients shown is then a polyphase power directional torque without any second order terms. The unused salients **163** and **167**, not shown in Fig. 7, may then be energized by such quantities as will produce the restraint desired for a particular application. These quantities may be system voltages where a predetermined relation is desired between a polyphase power directional torque and a torque dependent on certain voltages of the system from which the power directional torque is derived.

The connections shown in Fig. 7, as well as some variants thereof, are given in the following Table I, although this table is by no means intended to be exhaustive of the possible arrangements which can be evolved without departing from the spirit and scope of my invention. In this table, as well as throughout this application, E used with the sub-numbers 10, 20, and 30 indicates star voltages and with 12, 23, and 31 delta voltages.

Table I

Salient numbers	161	162	163	164	165	166	167	168
Arrangement	Electric quantities energizing windings							
A1	I_1-I_3	E_{23}	------	E_{12}	I_2-I_3	E_{23}	------	E_{31}
A2	I_1-I_3	E_{31}	------	E_{23}	I_2-I_3	E_{31}	------	E_{12}
A3	I_1-I_3	E_{12}	------	E_{31}	I_2-I_3	E_{12}	------	E_{23}
B1	I_1-I_2	E_{20}	------	E_{10}	I_2-I_3	E_{20}	------	E_{30}
B2	I_1-I_3	E_{30}	------	E_{20}	I_1-I_3	E_{30}	------	E_{10}
B3	I_1-I_2	E_{10}	------	E_{30}	I_2-I_3	E_{10}	------	E_{20}

These different arrangements vary the angle of maximum torque of the relay device. Obviously, the application of the different arrangements is

a matter of the characteristic desired for the type of protection in question. For example, arrangement A1 is suitable for ordinary transmission line protection, arrangement A2 may be applied to the control of network protectors in low voltage alternating current systems, and arrangement A3 under certain other conditions. Arrangement B1 is the equivalent of the so-called quadrature connection heretofore used with multiple disk polyphase relays, and arrangements B2 and B3 are the equivalents of the adjacent connections also used with such relays.

In the embodiment of my invention shown in Fig. 8, the circuit 1, 2, 3 is illustrated as being connected to the bus 30 through a circuit breaker 33 having a trip coil 34. The relay device embodying my invention is schematically shown as having a circuit controlling member 35 which is arranged to control contacts in the circuit of the trip coil 34, whereby to control the opening of the circuit breaker 33.

The salients 161, 163, 165, and 167 are energized by the line currents I_1, I_2, I_3, I_2, respectively, and consequently the torque due to the currents alone is zero. However, in accordance with my invention, in order to provide some voltage restraint, the salients 162, 164, 166, and 168 are energized by the voltages E_{23}, E_{23}, E_{12}, E_{31}, respectively. With this cyclic order of voltage energizations, the resultant torque due to voltage alone is not zero. Consequently, there is, in accordance with my invention, a predetermined voltage torque in addition to the power directional torque. Generally speaking, the connections are such that the voltage torque opposes the power directional torque under predetermined system conditions, for example, when power flows in a given direction, and assists when the power directional torque is reversed. The arrangement of the parts may be such that the voltage restraint predominates over the power torque under certain system conditions, for example, normal voltage conditions and power flow in a certain direction. As shown in Fig. 8, a relatively weak opening spring 36 may be used on the contact controlling member 35, but the strength of this spring is so small as to have substantially no effect on the calibration or pick-up of the relay.

In case of three-phase faults adjacent the relay location, the voltage windings become in effect short-circuited because the circuit voltages are practically zero. At such low circuit voltages, it is desirable that there be no net torque due to current alone. Ordinarily, some of the fluxes produced by the current windings may return through the salients which carry the voltage coils. Voltages are thus induced in the voltage coils. Consequently, currents flow in the voltage coils and the fluxes passing through these coils are modified thereby. Because of the phase displacement between these modified fluxes and the current fluxes, small torques appear which are normally balanced. However, if these small torques are not balanced, an undesirable net torque appears in one direction or the other. In accordance with my invention, I may balance these current bias torques by impedance adjustment of the circuits of the voltage coils through suitable means shown in Fig. 8 as adjustable resistors 37. Such balancing is particularly desirable for the three-phase fault condition, but the unbalance effect, even without the resistors, for example, may be substantially negligible if there is anything like normal voltage on some of the voltage windings.

Because of commercial limitations in manufacturing, certain variations or discrepancies may arise even though the windings are arranged in the theoretical order to balance out both the torques due to current alone and to voltage alone. This lack of balance may be compensated by the use of the impedance device 37 in the circuits of the potential coils, or the balance can be established by using flats or notches on the fixed stator. Such a notch is shown at 38 in Fig. 1. By varying the position of these flats or notches, the reluctance of the air gaps at the respective poles can be changed to effect the desired balancing action.

The connections shown in Fig. 8 as well as certain variants thereof are given in the following Table II, but here again this table is by no means intended to be exhaustive of the possible arrangements which can be evolved without departing from the spirit and scope of my invention.

Table II

Salient numbers	161	162	163	164	165	166	167	168
Arrangement	Electric quantities energizing windings							
C1	I_1	E_{23}	I_2	E_{23}	I_3	E_{12}	I_2	E_{31}
C2	I_1	E_{31}	I_2	E_{31}	I_3	E_{23}	I_2	E_{12}
C3	I_1	E_{12}	I_2	E_{12}	I_3	E_{31}	I_2	E_{23}
D1	I_1	E_{20}	I_2	E_{20}	I_3	E_{10}	I_2	E_{30}
D2	I_1	E_{30}	I_2	E_{30}	I_3	E_{20}	I_2	E_{10}
D3	I_1	E_{10}	I_2	E_{10}	I_3	E_{30}	I_2	E_{20}

In the above table, arrangements D1, D2, and D3 are the equivalent of the usual connections of polyphase relays for transmission line protection except for the voltage restraint feature. Thus, arrangement D1 is, so far as the polyphase power torque is concerned, the equivalent of the so-called quadrature connection and similarly, arrangements D2 and D3 are the equivalent of the adjacent connections. The connection D1 is illustrated in Fig. 9. The arrangement C1 is suitable for the ordinary transmission line protection applications, although it is probably no better on ground faults than the ordinary quadrature connection. In other words, incorrect operation might result if the directional polyphase load torque is greater than the ground fault directional torque or when generation is present at one end of the line only. The arrangement C2 may be applied to the control of network protectors for low voltage alternating current circuits, and arrangement C3 may prove useful under certain other conditions.

In order to obtain the maximum of protective features with the minimum amount of space and apparatus, I may provide, in accordance with my invention, a single unit device with only one current conducting rotor which embodies not only the power directional feature but also the ground power directional feature, and may in addition include the voltage restraint feature or not, as desired. Such an embodiment of my invention is illustrated in Fig. 10. In connection with the ground directional feature, some means of obtaining a zero phase sequence voltage E_0 such as the wye-open delta potential transformer 320 may be connected through the transformer 32 to be energized from the bus 30.

In this embodiment of my invention, the salients 161, 165, 166, and 168 are energized respectively by the circuit currents I_1, I_2, and the circuit voltages E_{12} and E_{23}. The fluxes in these

salients co-operate to produce the polyphase power directional torque. The windings on the salients **162** and **164** are connected in the open delta of the transformer **320** so as to be energized by the residual or zero phase sequence voltage of the system. The polarity of the connection of the winding on the salient **162** is reversed. Polarity reversals are indicated by a minus sign in Table III and subsequent tables. The winding on the salient **163** is connected to be energized by the residual current of the circuit and for this purpose is connected in the residual lead of the current transformers **31**. To produce the desired ground torque effect, additional winding turns may be used in the windings on the salients **162**, **163**, and **164**. The windings on these salients provide the fluxes which produce the ground directional torque. The salient **167** is energized by the voltage E_{31} reversed in polarity as indicated by the negative sign. The windings on the salients **166**, **167**, and **168** provide the desired voltage restraint. Examples of other ways in which the salient windings may be connected to provide polyphase and ground fault protection and also include voltage restraint are given in Table III, which, however, is not intended to be exhaustive of the possible arrangements which can be evolved without departing from the spirit and scope of my invention. In this table, $3E_0$ and $3I_0$ represent the actual ground fault voltage and current energizing the windings indicated and K is a proportionality factor which is dependent on design, for example, number of turns.

Table III

Salient numbers	161	162	163	164	165	166	167	168
Arrangement	Electric quantities energizing windings							
E1	I_1	$-3E_0$	$3KI_0$	$3E_0$	I_2	E_{12}	$-E_{31}$	E_{23}
E2	I_1	$-3E_0$	$3KI_0$	$3E_0$	I_2	E_{23}	$-E_{12}$	E_{31}
E3	I_1	$-3E_0$	$3KI_0$	$3E_0$	I_2	E_{31}	$-E_{23}$	E_{12}
F1	I_1	$-3E_0$	$3KI_0$	$3E_0$	I_2	E_{10}	$-E_{30}$	E_{20}
F2	I_1	$-3E_0$	$3KI_0$	$3E_0$	I_2	E_{20}	$-E_{10}$	E_{30}
F3	I_1	$-3E_0$	$3KI_0$	$3E_0$	I_2	E_{30}	$-E_{20}$	E_{10}
G1	I_1	$-3I_0$	$3KI_0$	$3I_0$	I_2	E_{12}	$-E_{31}$	E_{23}
G2	I_1	$-3I_0$	$3KI_0$	$3I_0$	I_2	E_{23}	$-E_{12}$	E_{31}
G3	I_1	$-3I_0$	$3KI_0$	$3I_0$	I_2	E_{31}	$-E_{23}$	E_{12}
H1	I_1	$-3I_0$	$3KI_0$	$3I_0$	I_2	E_{10}	$-E_{30}$	E_{20}
H2	I_1	$-3I_0$	$3KI_0$	$3I_0$	I_2	E_{20}	$-E_{10}$	E_{30}
H3	I_1	$-3I_0$	$3KI_0$	$3I_0$	I_2	E_{30}	$-E_{20}$	E_{10}

In the E and F arrangements, the ground fault directional response is based on zero phase sequence current I_0 and zero phase sequence voltage E_0 excitations, whereas in the G and H arrangements the ground fault directional response is based on two separately energized zero phase sequence excitations which may be obtained in various ways well known to the art. The applications of the arrangements **E1**, **E2**, and **E3** are like those of the arrangements **C1**, **C2**, and **C3** in Table II, except of course that there is the addition of the zero phase sequence power term to give the certainty of ground fault response regardless of magnitude of load power or location of generation. Similarly, the applications of the arrangements **F1**, **F2**, **F3** are like those of the arrangements **D1**, **D2**, **D3**, Table I, except for the ground fault response feature. Whether the ground fault response is on the basis of current and potential or current and current is, as is well known to the art, a matter of choice for the particular application in hand. Accordingly, the arrangements G and H may be chosen where current-current excitation is desired. The application of the arrangements **G1**, **G2**, **G3**, is like that of arrangements **C1**, **C2**, and **C3** in Table II, except for the zero phase sequence power term to give the desired certainty of ground fault response regardless of load power. Similarly, the applications of the arrangements **H1**, **H2**, **H3** are like those of arrangements **D1**, **D2**, **D3**, except for the ground fault response feature.

Fig. 11 illustrates another embodiment of my invention in which the resultant torque is a polyphase directional torque with voltage restraint. The diametrically opposite salients **161** and **165** are energized by the currents I_1 and I_2, respectively, so that there are no second order current terms to introduce any undesired current torque; the salients **162**, **163**, **164**, **166**, **167**, **168** are energized by the voltages $-E_{23}$, E_{31}, $-E_{12}$, E_{12}, E_{31}, and E_{23}, respectively. The resultant polyphase power directional torque arises from the action between the salients **161** and the adjacent salients **162** and **168** and between the salient **165** and the adjacent salients **164** and **166**. The restraining voltage torque arises from the action between the diametrically opposite salients **163** and **167** and the salients respectively adjacent these. Accordingly, with this arrangement, the result is a polyphase power directional torque with voltage restraint. Examples of other ways in which the salient windings may be connected to provide polyphase directional torque with voltage restraint are given in Table IV, which, however, is not intended to be exhaustive of the possible arrangements which can be evolved without departing from the spirit and scope of my invention.

Table IV

Salient numbers	161	162	163	164	165	166	167	168
Arrangement	Electric quantities energizing windings							
L_1	I_1	$-E_{23}$	E_{31}	$-E_{12}$	I_2	E_{12}	E_{31}	E_{23}
L_2	I_1	$-E_{31}$	E_{12}	$-E_{23}$	I_2	E_{23}	E_{12}	E_{31}
L_3	I_1	$-E_{12}$	E_{23}	$-E_{31}$	I_2	E_{31}	E_{23}	E_{12}

The application of these respective arrangements **L1**, **L2**, **L3** is the same as the arrangements **C1**, **C2**, and **C3**, as shown in Table II.

In the various modifications of my invention and particularly those involving the use of zero phase sequence quantities, it will be observed that the flux produced by a coil crosses the air gap, thereby entering the rotor, and may return by any path in inverse proportion to the reluctance of that path. Such path may be the salient of another coil and consequently extraneous torques may appear. These are substantially eliminated, however, by making the end plate **21**, which supports the stator **18**, as well as the hub support **24** therefor, of magnetic material, as disclosed in the Bancker application supra. In this way, there is provided a shunt flux return path whereby the residual fluxes can return by innocuous paths without reacting upon other fluxes to produce unwanted torques.

While I have shown and described my invention in considerable detail, I do not desire to be limited to the exact arrangements shown, but seek to cover in the appended claims all those modifications that fall within the true spirit and scope of my invention.

What I claim as new and desire to secure by Letters Patent of the United States is:

1. In combination, a polyphase alternating cur-

rent system and an electroresponsive device comprising a single movable member having an electric current conducting path and electromagnetic means for controlling the movement of said member in accordance with the magnitudes of and the phase displacements between predetermined electric quantities of two groups of coexisting polyphase quantities derived from said system including a multipole magnetic member, windings thereon connected to be energized by said groups of quantities in a predetermined order to provide a torque proportional to a predetermined function of said quantities, certain of said windings being energized by predetermined quantities from one group to provide a counter torque opposed to said first torque under predetermined conditions of the system.

2. In combination, a polyphase alternating current system, an electroresponsive device comprising a single rotor having a closed electric current conducting path and means for actuating said rotor in accordance with the magnitudes of and the phase displacements between predetermined electric quantities of two groups of coexisting polyphase quantities derived from said system including a magnetic member comprising a plurality of radially disposed salients having their extremities concentric with the conducting path of said rotor, means for energizing only two diametrically opposite salients by quantities from one polyphase group including windings on said two salients, the torque effect of said windings alone on said rotor being substantially nothing, and windings on other salients connected to be energized in a predetermined order by electric quantities from the other polyphase group, the resultant torque effect of all of said windings on said rotor being proportional to the sum of the products of the quantities energizing adjacent salients and the phase displacement between said quantities.

3. In combination, a polyphase alternating current system, an electroresponsive device comprising a single rotor having a closed electric current conducting path, and means for actuating said rotor in accordance with the magnitudes of and the phase displacements between predetermined electric quantities of two groups of coexisting polyphase quantities derived from said system, including a magnetic member comprising a plurality of radially disposed salients having their extremities concentric with the conducting path of said rotor, windings on certain of said salients connected to be energized in a predetermined order by quantities from one of said polyphase groups, the torque effect of said windings alone being substantially zero, and windings on certain other salients connected to be energized in a predetermined order by quantities from the other polyphase group to exert a torque on said rotor and the resultant torque effect on the rotor of the interaction of the windings energized by the polyphase quantities in the two groups being dependent upon the product of the quantities energizing adjacent salients and the phase displacement between said quantities.

4. In combination, an n-phase alternating current system, a hollow magnetic stator having $4(n-1)$ inwardly projecting salients, a rotor having an electric current conducting path centrally positioned relatively to the inner ends of said salients, windings on certain salients connected to be energized in a predetermined order by one set of n-phase electric quantities of said system, the resultant torque effect of said windings on said rotor being zero, and windings on the other salients connected to be energized in a predetermined order by another set of n-phase electric quantities of said system to exert a torque effect on said rotor, the resultant torque effect of adjacent windings energized by quantities from said two different sets of polyphase quantities being dependent on the summation of the products of the quantities energizing said windings and the angular displacements of said quantities.

5. In combination, a three-phase alternating current system and a relay comprising a single rotatable current conducting member, electromagnetic means for actuating said member in accordance with a component of the polyphase power of the system including a multipole magnetic member and windings thereon connected to be energized by the currents and the voltages of the system in a predetermined order, certain of said windings being energized by predetermined voltages of the system to provide a torque opposed to said power torque under predetermined system conditions.

6. In combination, a polyphase alternating current system and an electroresponsive device comprising a single rotatable current conducting member and electromagnetic means for actuating said member in accordance with the magnitudes of and the phase displacements between the currents and the voltages of the system including a multipole magnetic member and windings thereon connected to be energized by said currents and voltages in a predetermined order to provide a torque dependent upon the polyphase power of the system, and a voltage restraint torque under predetermined conditions of the system.

7. In combination, a polyphase alternating current system and a device comprising a single rotatable current conducting member, electromagnetic means for actuating said member in accordance with the magnitudes of and the phase displacements between the currents and voltages of said system including a multipole magnetic member and windings thereon connected to be energized by said currents and voltages in a predetermined order to provide a torque which is proportional to a component of the power of said system, certain of said windings being energized by predetermined voltages of the system to provide a torque opposed to said power torque under predetermined conditions of the system.

8. In combination, a three-phase alternating current system, an electroresponsive device comprising a single rotor having a closed electric current conducting path and means for actuating said rotor in accordance with the polyphase power of said system including a magnetic member comprising a plurality of radially disposed salients having their extremities concentric with the conducting path of said rotor, windings on certain of said salients connected to be energized in a predetermined order by currents derived from said system currents, the torque effect of said current energized windings alone being substantially zero and windings on certain other salients connected to be energized in a predetermined order by voltages of said system, the torque effect of said windings alone having a predetermined value and the resultant torque effect on the rotor of the interaction of the current and voltage energized windings being dependent on a component of the polyphase power of said system.

9. In combination, a polyphase alternating current system and an electroresponsive device comprising a single rotatable current conducting member and electromagnetic means for actuating said member in accordance with the magnitudes of and the phase displacements between the currents and the voltages of the system including a multipole magnetic member and windings thereon connected to be energized by said quantities in a predetermined order to provide a torque dependent on the polyphase power of the system and the zero sequence power of the system.

10. In combination, a polyphase alternating current system and an electroresponsive device comprising a magnetic stator having a plurality of inwardly projecting salients, a magnetic member centrally positioned relatively to and spaced from the inner ends of said salients, a rotor of electric current conducting material between said central magnetic member and the inner ends of said salients, means for actuating said rotor in accordance with the polyphase power of the system and the zero sequence power of the system including windings on said stator connected to be energized by the currents and the voltages of the system in a predetermined order, and a shunt magnetic path for the residual flux of the windings producing the zero sequence power torque.

11. In combination, a three-phase alternating current system and a relay comprising a single rotatable current conducting member, electromagnetic means for actuating said member including a multipole magnetic member and windings thereon connected to be energized by said quantities in a predetermined order to provide a torque dependent on a component of the polyphase power of the system and a voltage restraint torque opposed to said polyphase power torque under predetermined system conditions and further windings on said member connected to be energized in accordance with zero phase sequence quantities of the system to provide a torque dependent on the zero phase sequence power of the system.

12. In combination, a polyphase alternating current system and an electroresponsive device comprising a single rotatable current conducting member, electromagnetic means for actuating said member in accordance with the magnitudes of and the phase displacements between the currents and the voltages of the system including a multipole magnetic member and windings thereon connected to be energized by said quantities in a predetermined order to provide a torque dependent on a component of the polyphase power of the system, and a voltage restraint torque opposed to said polyphase power torque under predetermined conditions of the system, and further windings on said member energized from said system to provide a third torque dependent on the zero sequence power of the system.

13. In combination, a polyphase alternating current system, an electroresponsive device comprising a movable member having an electric current conducting path, and means for controlling the movement of said member in accordance with a zero phase sequence quantity derived from said system including a magnetic member having a plurality of salients, a winding on one of said salients energized by said zero phase sequence quantity and a return magnetic path independent of said magnetic member for the flux induced in said salient by said zero phase sequence quantity.

14. In combination, two polyphase systems of alternating current quantities, an electroresponsive device comprising a single rotatable electric current conducting member, and means for actuating said rotatable member in accordance with the magnitudes of and the phase displacements between predetermined quantities of said two systems including a magnetic member comprising a plurality of radially disposed salients having their extremities concentric with said rotatable member, means for energizing each of two diametrically opposite salients by a function of at least two quantities from one polyphase group, including windings on said two salients, the torque effect of said windings alone on said rotatable member being substantially nothing, and windings on other salients connected to be energized in a predetermined order by electric quantities from the other polyphase group, the resultant torque effect of all of said windings on said rotor being proportional to the sum of the products of the quantities energizing adjacent salients and the phase displacement between said quantities.

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