Aug. 29, 1967 H. J. CALHOUN 3,339,115

DIRECTIONAL RELAY APPARATUS

Filed May 17, 1965

5 Sheets-Sheet 1

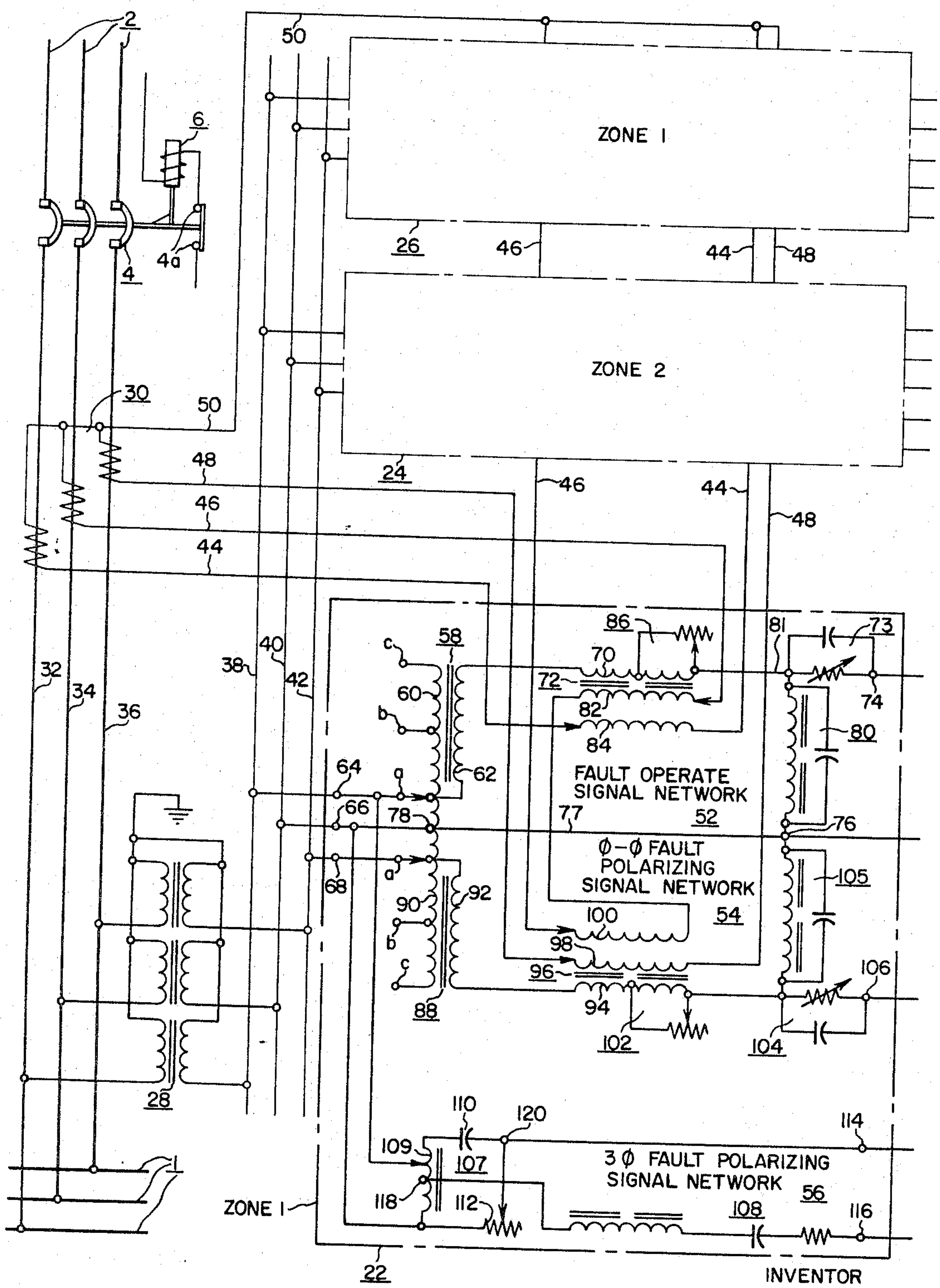

FIG. 1A.

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DIRECTIONAL RELAY APPARATUS

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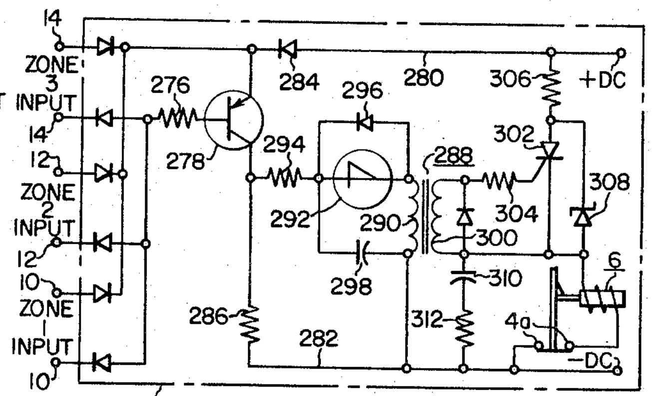


FIG.2.

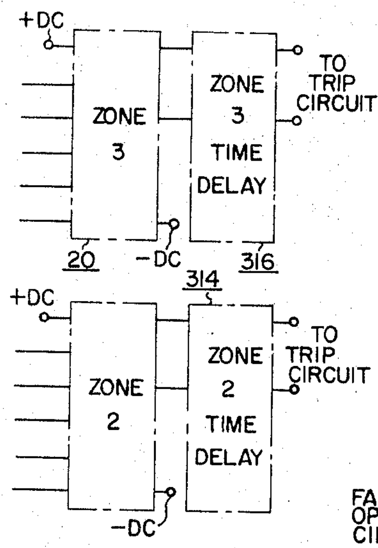
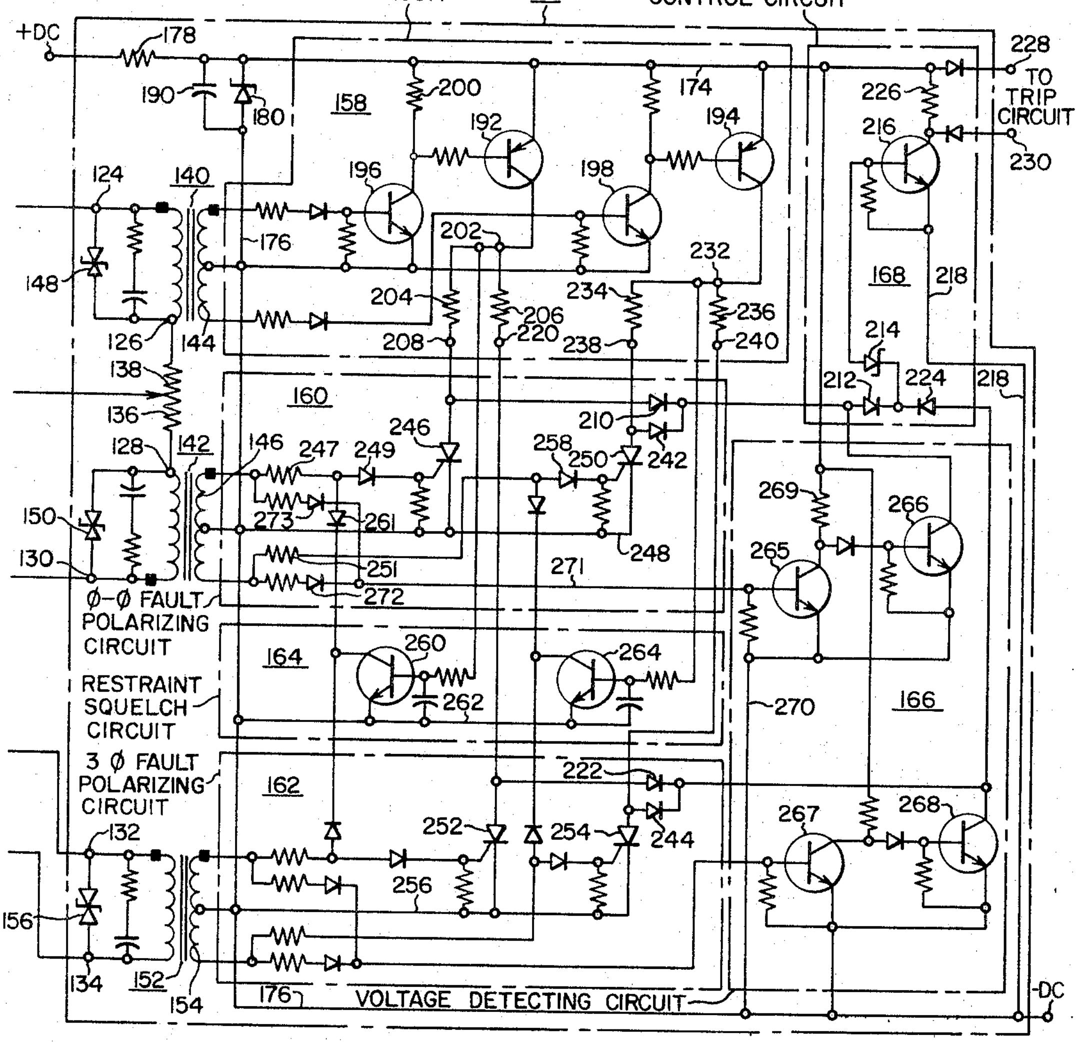


FIG.1B.



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DIRECTIONAL RELAY APPARATUS

Filed May 17, 1965

5 Sheets-Sheet 3

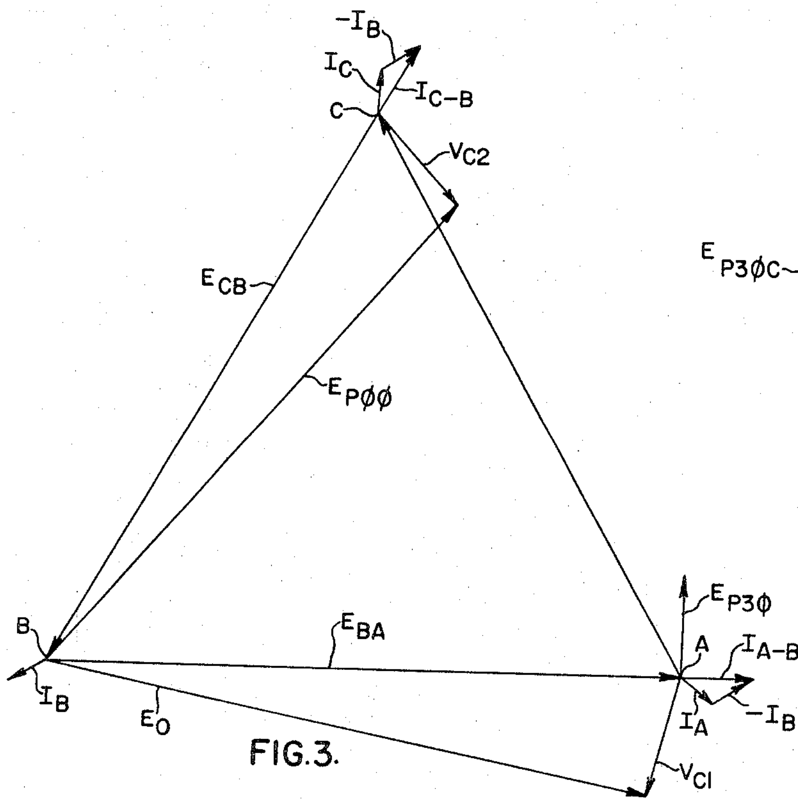

FIG. 3.

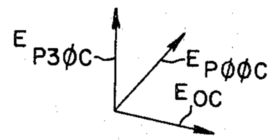

FIG. 3A.

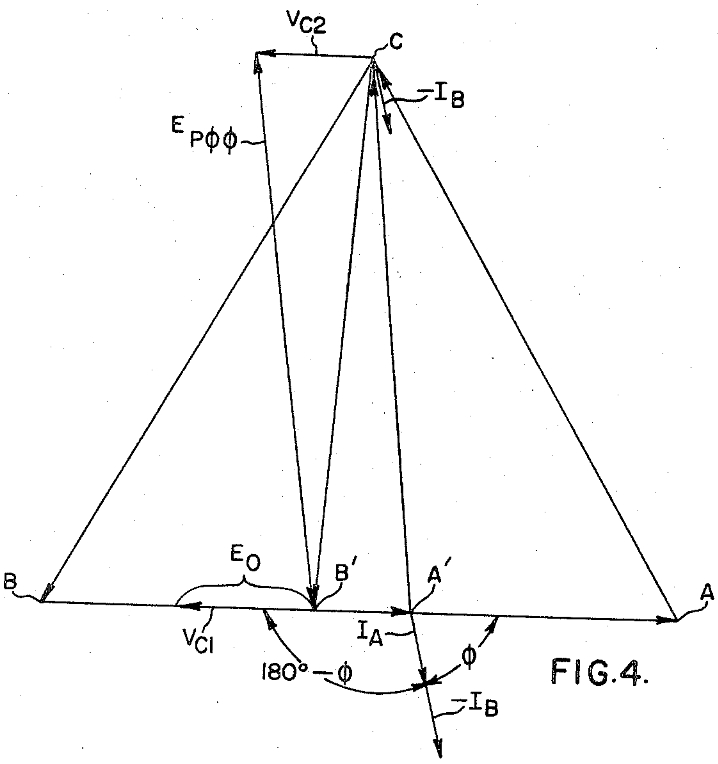

FIG. 4.

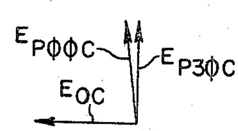

FIG. 4A.

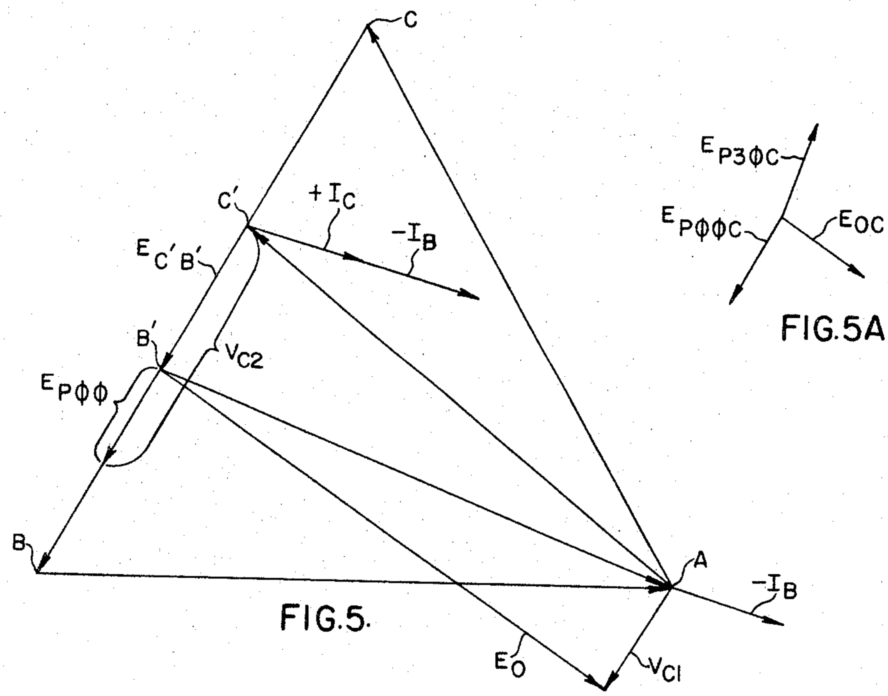

FIG. 5.

FIG. 5A.

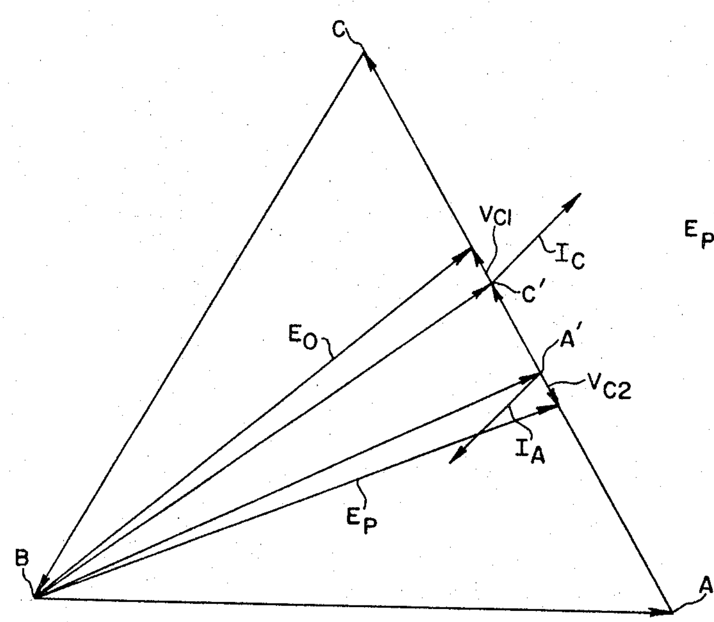

FIG. 6.

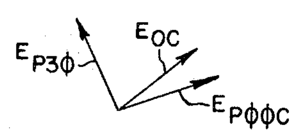

FIG. 6A.

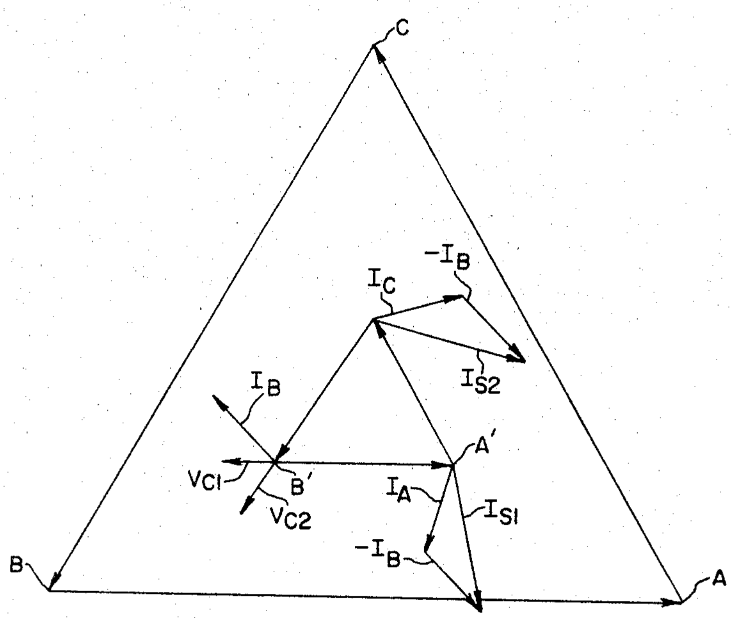

FIG.7.

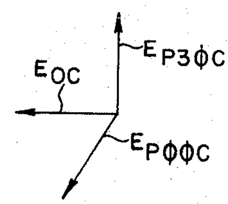

FIG.7A.

United States Patent Office

3,339,115

Patented Aug. 29, 1967

3,339,115
DIRECTIONAL RELAY APPARATUS

Howard J. Calhoun, Millington, N.J., assignor to Westinghouse Electric Corporation, Pittsburgh, Pa., a corporation of Pennsylvania

Filed May 17, 1965, Ser. No. 456,209
29 Claims. (Cl. 317—36)

This invention relates generally to relaying apparatus and more particularly to the type known as distance relays.

An object of this invention is to provide a relaying apparatus using static type circuit components.

A further object of this invention is to provide such an apparatus which has a minimum number of components.

A still further object of this invention is to provide a fault sensing network utilizing not more than two compensaters and which apparatus will respond to both line to line and three-phase faults.

A still further object of this invention is to provide a relaying network in which the phasing of single operating quantity with respect to one or the other of a pair of polarizing quantities is relied upon to provide a tripping signal upon the occurrence of a fault in the protected network.

Another object is to provide an improved trip controlling network which will remain ineffective as long as a predetermined one of three control signals lags the phase of the other two thereof but which will actuate the trip mechanism whenever this particular signal leads either or both of the other two signals.

Other objects of this invention will be apparent from the description, the appended claims and the drawings in which drawings:

FIGURE 1 (comprising FIGS. 1A, 1B) shows a schematic diagram of a relaying apparatus embodying the invention.

FIG. 2 is a schematic diagram of the amplifying network for actuating the breaker trip coil.

FIG. 3 and 3A are vector diagrams illustrating a normal non-faulted network operation;

FIGS. 4 and 4A are vector diagrams illustrating a first type of line to line fault.

FIGS. 5 and 5A are vector diagrams showing a second type of line to line fault.

FIGS. 6 and 6A are vector diagrams illustrating a third type of line to line fault; and,

FIGS. 7 and 7A are vector diagrams illustrating a three-phase fault.

Referring to the drawings by characters of reference, the number **1** indicates generally a three-phase power distribution network having a branch network **2** connectable and disconnectable from the network **1** by means of a usual breaker **4** having a trip coil **6** operated by a trip coil amplifying network **8** shown in FIG. 2. The amplifying network **8** has at least one pair of input terminals and in the instant shown has three pairs thereof **10**, **12** and **14** for connection to the output terminals of the trip coil actuating networks **16**, **18** and **20** of the three protection zones.

These trip coil actuating networks **16**, **18** and **20** are controlled respectively by distance logic networks **22**, **24** and **26** of zones **1**, **2** and **3** shown in FIGURE 1A. These distance logic networks are identical to each other except for certain adjustments which permit the magnitudes of the control quantities developed therein to be of different relative magnitudes with respect to the values of the current and voltage in the power network **1** at the station location that the signals are derived. The voltage and current quantities may be sensed in the usual manner as by the transformer arrays **28** and **30**. The

adjustment of the zone **1** network **22** is such that the control quantities are large with respect to the line quantities whereby the network **22** responds to faults which occur a first predetermined distance from the breaker **4**. Zone **2** is adjusted to respond to faults occurring further beyond the breaker and zone **3** is adjusted to respond to faults still further beyond. Normally, in accordance with prior operating practice well known to those skilled in the art, the zones will be separated by the breakers and supplied with electrical energy from additional power sources, and similar as for example to that discussed in Patent No. 2,873,460. Since the zone **2** and zone **3** actuating and logic networks are identical to the zone **1** networks a detailed description of only the zone **1** networks will be given.

The potential transformer array **28** comprises three transformers having their primary windings connected in Y to the conductors **32**, **34** and **36** of the branch network **2** and having the neutral terminal connected to ground. The secondary windings of this array **28** are Y connected to the control busses **38**, **40** and **42** and the neutral terminal is grounded. The potential derived electrical quantities appearing between the conductors **38**, **40** and **42** are phased so that the vector quantities representing these quantities have the same relation with respect to each other as the vector quantities representing the voltages of the supply conductors **32**, **34** and **36** of the branch network **2**.

The current transformer array **30** comprises three Y connected current transformers associated with the three conductors **32**, **34** and **36** respectively and developing current derived quantities which are representative of the current flowing in the branch network **2**. These transformers energize individual current quantity conducting conductors **44**, **46** and **48**. A common current quantity conductor **50** is connected to the neutral connection of the array **30**.

The distance logic networks comprise a fault operate signal network **52**, a line to line fault polarizing signal network **54**, and a three-phase fault polarizing signal network **56** energized from the potential and current derived quantities supplied from the voltage and current transformer arrays **28** and **30**. The potential quantity is supplied to the fault operate signal network **52** through a transformer **58** having a tapped primary winding **60** and energized from first and second potential quantity input terminals **64** and **66** connected respectively to the buses **38** and **40**. By a suitable selection of the tap of the winding **60** the volts per turn of a secondary winding **62** may be determined and thereby the magnitude of the potential quantity supplied to the network **52** relative to the potential between the conductors **32** and **34**. The connection of the terminal **64** and the winding **60** for zone **1** is to tap *a* for zone **2** is to tap *b* and to zone **3** is to tap *c* as illustrated in my said patent to permit the use of the same distance logic network for each of the zones **1**, **2** and **3**. The transformer **58** may serve to isolate the network **52** from the conductors or one terminal of the winding **62** may be connected as shown to an intermediate tap of the primary winding **60** to reduce the turns required by the winding **62**. The other terminal of the winding **62** is connected through the output winding **70** of a compensator **72** and a transient supressing network **73** to the one output control terminal **74** of a first pair of output terminals **74–76** of the distance logic network **22**. The second control terminal **76** of the first pair of output terminals is connected by a conductor **77** to a common terminal **78** of the winding **60** of transformer **58** and winding **90** of a transformer **88** to complete the secondary circuit of the transformer **58**. The primary circuit is completed by connecting terminal **78** to the input terminal **66**.

If desired, a transient suppressing network **80** may be connected between the output terminal **76** and the common connection **81** of winding **70** to the transient suppressing network **73**.

The compensator **72** may be of the same type as the compensator T of my said patent. As such it may take the form of a transformer having a core with an air gap, sometimes known as a mutual inductance, and having compensating windings **82** and **84** inductively coupled by means of the core to the output winding **70**. The compensator **72** vectorially adds the quantities applied to the windings **82** and **84** to provide a current derived summed quantity for modifying the potential quantity supplied by the transformer **58**. This summed quantity is phase shifted an amount equal to the magnitude of the predetermined characteristic phase angle of the branch network **2** by a phase shifting arrangement **86** whereby the compensating quantity applied to the output terminals of the winding **70** is properly phased as will be described in greater detail below. The compensator **72** is a summing device which provides a compensating output quantity for addition to the potential derived quantity as may be represented by the vector V_{c1} in any of FIGS. 3 through 7A. The phase shifting arrangement may take the conventional form of a resistor shunting a portion of the winding **70**.

The line to line fault polarizing signal network **54** is similar to the fault operate signal network **52** and comprises the transformer **88** having the tapped winding **90** and a secondary winding **92**. The adjustable tap of the winding **90** is connected to a third input terminal which is connected to the conductor **42**. As stated above, the other terminal of the winding **90** is connected to the common terminal **78** and to the second potential quantity input terminal **66**. The winding **90** is thereby energized from the third potential derived quantity. One end of the winding **92** is connected to a tap on the winding **90** and the other end thereof is connected through the output winding **94** of a second compensator **96** and a transient suppressing network **104** to one output control terminal **106** of a second pair of output terminals **76–106** of network **22**. The second compensator **96** like the compensator **72** is provided with compensating windings **98** and **100** and a phase shifting arrangement **102**. The first control terminal of this second pair of control terminals is common with the second control terminals **76** of the first pair of control terminals, and connects with the common terminal **78**. A transient suppressing network **105** may be connected between the terminal **76** and the connection between the network **104** and the winding **94**.

In order to provide the desired output of compensating quantities of the compensators **72** and **96**, certain of the current derived quantities provided by the current transformer array **30** are caused to flow through the compensating windings **82, 84, 98** and **100** as indicated by the vector diagrams. More specifically, windings **84** of compensation of the logic networks **22, 24** and **26** are connected in series with each other and with the conductor **44** to the common conductor **50**. The windings **82** and **100** of the compensators of the logic networks are connected in series with each other with current conductor **46** to the common conductor **50**. Similarly the windings **98** of the logic network are connected in series with each other and the conductor **48** to the common conductor **50**. The direction of the current quantities through the compensating windings **82** and **84** of the compensator **72** is such that the vector V_{C1} representing the quantity of the output terminal of the winding **70** is the vector sum of the positive vector I_A which represents the current derived quantity that is proportional to the magnitude of the current in the conductor **32** and the negative vector $-I_B$ which represents the current derived quantity that is proportional to the current in the conductor **34**, and phase shifted by an amount determined by the network **86**. Similarly the directions of the current derived quantities through the windings **98** and **100** of the compensator **96** is such that vector V_{C2} representing the quantity of the output terminals of the winding **94** is the vector sum of the positive vector I_C which represents the current derived quantity that is proportional to the current in the conductor **36** and the negative vector $-I_B$ which represents the current derived quantity that represents the current in the conductor **34** and phase shifted as determined by the network **102**. This arrangement, with the phasing provided by the arrangements **86** and **102** is vectorially illustrated under non-fault conditions by the vector diagram of FIG. 3. The phase shift imparted by the phase shifting arrangements **86** and **102** is preferably the impedance angle of the branch network **2**. The phase shifting apparatus adds vector quantity V_{C2} to the point C. Since the vector quantity V_{C1} is added to the potential of the terminal **64** (point A), the output operate quantity appearing between the first and second terminals **74** and **76** of the first pair of output terminals may be represented by the vector F_O and the output polarizing quantity appearing between the first and second control terminals **76** and **106** of the second pair of output terminals may be represented by the vector $E_{P\phi\phi}$ which is the vector quantity resulting from the addition of the vector quantity V_{C2} to the point C.

The three-phase fault polarizing signal network **56** provides a voltage which leads the voltage between the conductors **34–32** by an angle which is illustrated as being ninety degrees and is vectorially illustrated by the vector $E_{P3\phi}$. For this purpose the network **56** comprises a phase shifting network **107** and a memory network **108**. The phase shifting network **107** comprises an impedance having a center tapped winding **109**, a capacitor **110** and a variable resistance **112**. The winding **109** is connected between the input terminals **64** and **66** whereby it is energized with a voltage derived quantity representing the potential between conductors **34** and **32** and represented in the vector diagrams by the vector E_{BA}. As indicated, the connection from terminal **64** is adjustable to control the magnitude of the output potential of the network **107**. The capacitor **110** and the variable resistor **112** are connected in series between the upper and lower end terminals of the winding **109**. The output potential of the phase shifting network **107** is derived from the center tap **118** of the winding **109** and the common connection or terminal **120** between the capacitor **110** and the resistor **112**.

The memory network **108** comprises an inductor and a capacitor connected in series between the terminal **116** and the center tap **118**. This network is tuned to the frequency of the network **1** so that it will provide for a continued energization of the control terminals **114** and **116** for a short interval following termination of the voltage appearing between the conductors **32** and **34**, such as may occur in the event of a fault between these two conductors (A–B fault).

The control terminals **74, 76, 106, 114** and **116** of the logic network **22** are connected respectively to input terminals **124, 126–128, 130, 132** and **134** of the trip coil actuating network **16**. The connection from the terminal **76** to the terminals **126** and **128** includes a balancing resistor **136** having its resistor terminals connected between the terminals **126** and **128** and its movable tap **138** connected to the terminal **76**. The network **16** comprises three transformers **140, 142** and **152** having their primary windings individually connected between the terminals **124–126, 128–130** and **132–134** respectively.

As will be brought out in greater detail below, it is desirable that the output voltages supplied by the transformers **140, 142** and **152** remain above a critical effective magnitude substantially throughout the entire 180 degrees of each half cycle and that such voltage remains within reasonable limits. A suitable wave shape is a square wave. A convenient structure for obtaining such a voltage wave is the provision of clipping devices which will limit the magnitude of the potential supplied to the primary windings of the transformers. As diagrammatically illustrated this is accomplished by connecting two oppositely poled Zener diodes **148**, **150** and **156** in shunt with the primary windings of the transformers **140**, **142** and **152** respectively. Transient suppressing networks comprising a capacitor connected in series with a resistor across the primary windings of these transformers may be used to eliminate or reduce the occurrence of spurious signals at the output or secondary windings **144**, **146** and **154**.

The trip coil actuating network **16** comprises a fault operate circuit **158**, a line to line fault polarizing circuit **160**, a three-phase fault polarizing circuit **162**, a restraint squelch circuit **164**, a voltage detecting circuit **166** and a trip amplifier control circuit **168**. Unidirectional power for the trip coil actuating network is provided from a suitable source of supply such as the station battery and is diagrammatically indicated by terminals identified by +DC and −DC. In order that the voltage between the positive and negative DC buses **174** and **176** may be held at a desired constant value, the bus **174** is connected to the +DC terminal through a voltage dropping resistor **178** and to the negative bus **176** through a voltage regulating device which may be of a Zener diode **180**. A capacitor **190** is connected between the buses **174** and **176** to aid in the attainment of the constant potential therebetween.

The fault operate circuit **158** is actuated from the center tapped secondary winding **144** of the transformer **140** which controls the conductive condition of the transistors **192** and **194**; the transistor **192** being rendered conductive during the polarity-positive half cycles and the transistor **194** being rendered conductive during the polarity-negative half cycles of the output signal of the transformer **140**. Amplifying transistors **196** and **198** are utilized to amplify the output signals of the winding **144** and control the transistors **192** and **194**. The base of the transistor **196** is connected to upper terminal of the winding **144** through a current limiting resistor and diode and the emitter is connected to the center tap of the winding **144**. The collector-emitter circuit of the transistor **196** extends from the positive bus **174** through a voltage dropping resistor **200** to the negative bus **176**. The control circuit of the transistor **192** extends from the positive bus **176**, the emitter-base of the transistor **192**, a current limiting resistor, and the collector-emitter circuit of the transistor **196** to the negative bus **176**. The emitter of transistor **192** is connected to the positive bus **174** and its collector is connected to a common terminal **202** of a pair of voltage dropping resistors **204** and **206** connected between the terminal **202** and a pair of terminals **208** and **220** respectively. The terminal **208** is connected through a first diode **210**, a second diode **212** and a Zener diode **214**, to the base of a transistor **216** of the trip amplifier control circuit **168**. The emitter of the transistor **216** is connected by a conductor **218** to the negative bus **176**.

The free end of the resistor **206**, which is energized concurrently with the resistor **204**, is connected to a terminal **220** and therefrom through diodes **222** and **224** and the Zener diode **214** to the base of the transistor **216**. The emitter of the transistor **216** is connected by a conductor **218** to the negative bus **176** and the collector is connected through a voltage establishing resistor **226** to the positive bus **174**. When transistor **216** conducts, a signal will be established between the output terminals **228** and **230**. These terminals **228** and **230** are connected to the upper and lower input terminals **10** respectively of the amplifier network **8**. As will be described below, the conduction of transistor **216** results in energization of the trip coil **6** of the circuit breaker **4** and opening of the circuit breaker contacts to disconnect the branch **2** from the three-phase power network **1**.

The transistor **194**, which functions during the opposite half cycle to the transistor **192**, has its emitter connected to the bus **174** and its collector connected to a common terminal **232** of a pair of resistors **234** and **236**. The other end terminals of the resistor are connected to terminals **238** and **240** respectively. The terminal **238** is connected through diodes **242**, **212** and **214** to the base of the transistor **216**. Similarly, the terminal **240** is connected through diodes **244**, **224** and **214** to the base of the transistor **216**.

Conduction of the transistor **194** is controlled by the transistor **198** and for this purpose the base thereof is connected to the negative bus **176** through the collector of transistor **198** and the usual current limiting resistor. The base of the transistor **198** is connected through a diode and current limiting resistor to the lower end terminal of the transformer winding **144** and its emitter is connected directly to the center tap connection thereof.

In order to prevent energization of the trip coil **6** except in response to fault on the network branch **2**, the terminals **208**, **220**, **238** and **240** are selectively directly connected to the negative bus **176** by the polarizing circuits **160** and **162** in shunt with the base circuit of the transistor **216**. Since these shunt circuits inevitably have some resistance therein, a Zener diode **214** is selected which has a breakover potential which is in excess of such voltage drop. This assures that no base current will flow to the transistor **216** from any of the terminals **208**, **220**, **238** and **240** which are shunted to the negative bus **176**.

The shunt circuit for the terminal **208** extends therefrom through a discontinuous type control device **246** such as a silicon controlled rectifier and a branch bus **248** to the negative bus **176**. The shunt circuit for the terminal **238** extends therefrom through another discontinuous control device **250** such as the silicon controlled rectifier and bus **248** to bus **176**. Likewise, the shunt circuits for the terminals **220** and **240** extend through discontinuous control valves **252** and **254** respectively which may be silicon controlled rectifiers and a branch bus **256** of the three-phase fault polarizing circuit **162** to the negative bus **176**.

As will be brought out more clearly below, the operation of the relaying controlling apparatus with an unfaulted condition of the network **2** is such that the phase of the output signals of the transformers **142** and **152** lead the phase of the output signal of the transformer **140** whereby the controlled rectifiers **246**, **250**, **252**, and **254** are gated into conductivity prior to the time that the transistors **192** and **194** are rendered conducting. With such a phasing, the potential of the terminals **208**, **238**, **220** and **240** cannot increase substantially above ground potential when the transistors **192** and **194** actually conduct. The breaker **4** will therefore remain in its circuit closing position to connect the network branch **2** to the network. The gate of the controlled rectifier **246** is connected to the upper terminal of the winding **146** through a current limiting resistor **247** and a diode **249** while the cathode is connected to the center terminal through a bus **248**. A usual shunting resistor shunts the gate and cathode. The gate of the controlled rectifier **250** is connected to the lower terminal of winding **146** through another current limiting resistor **251** and a diode **258** and the cathode is connected to the branch bus **248**. A shunting resistor is connected between the gate and cathode of the rectifier **250**. During the periods in which the upper terminal of the winding **146** is positive with respect to the center tap connection, the gate of the controlled rectifier **246** will be maintained in condition for anode to cathode conduction of the controlled rectifier **246** upon the conduction of transistor **192** and similarly during the periods in which the lower terminal of the winding **146** is positive with respect to the center tap, the controlled rectifier **250** will be in readiness to conduct upon conduction of the transistor **194**. The controlled rectifiers **246** and **250** are of the discontinuous control type in that when once rendered conductive they will conduct as long as anode cathode voltage is maintained thereacross. Therefore these controlled rectifiers **246** and **250** will continue to conduct and hold the terminals **208** and **238** substantially at ground potential for the time period that the transistors **192** and **194** conduct even though the gate signal subsequently terminates.

Similarly, the controlled rectifiers **252** and **254** have their gate and cathode circuits connected to the transformer winding **154** whereby these rectifiers are rendered in a conducting condition whenever the transformer **152** is energized. These rectifiers **252** and **254** act in a manner similar to the rectifiers **246** and **250** and maintain the companion terminals **220** and **240** substantially at ground potential when they conduct.

The restraint squelch circuit **164** is provided to shunt the gate current from the controlled rectifiers **246** and **250** in instances in which the transistors **192** and **194** are rendered conducting prior to the rendering of the controlled rectifiers **246** and **250** conducting. The restraint squelch circuit **164** includes two transistors **260** and **264** with their base emitter circuits connected between the terminals **202** and **232** and the negative bus **176** through the usual current limiting resistors. The collector of the transistor **260** is connected to the common connection of the resistor **247** and diode **249** through a diode **261**. The collector is also connected to the common connection of resistor and diode which connects upper terminal of the transformer **152**. This connection includes a diode to prevent current flow except toward the transistor **260**. The emitter of the transistor **260** is connected to a negative branch bus **262**. When the transistor **192** conducts, the terminal **202** is elevated in potential and base current flows through the transistor **260** rendering it conductive and thereby effectively shunting any gate current from the controlled rectifiers **246** and **252**. Similarly, the base of the transistor **264** is connected through a usual current limiting resistor to the terminal **232**, the emitter is connected to the branch bus **262** and the collector is connected through diodes to the gate circuits of the controlled rectifiers **250** and **254**. Therefore whenever the transistor **194** conducts, the transistor **264** is rendered conductive whereby the potential of the gates of the controlled rectifiers **250** and **254** are maintained at substantially the potential of the negative bus **176** and the controlled rectifiers **250** and **254** cannot be rendered conducting. With this arrangement the effect of the conduction of the transistors **192** and **194** cannot be nullified if they are rendered conducting prior to the rendering of any of the controlled rectifiers **246**, **250**, **252** and **254**.

The voltage detecting circuit **166** prevents an incorrect tripping of the breaker **4** by the operate circuit even though one or both of the polarizing voltages established by the transformers **142** and **152** should disappear. This circuit **166** includes the transistors **265**, **266**, **267** and **268**. Transistor **265** controls the conduction of transistor **266** each of which has its emitter connected to negative branch bus **270**. The collector of transistor **265** is connected through a voltage dropping resistor **269** to the positive bus **174**. The collector of the transistor **266** is connected to the common connection of the diodes **210** and **212**. Base current for the transistor **265** is derived from the transformer **142** through the connection **271** and the diodes **272** and **273**, and will conduct at all times that the transformer **142** is energized. Since the base of the transistor **266** is connected to the common connection of the resistor **269** and the collector of the transistor **265**, the transistor is normally maintained non-conducting. If, however, the output voltage of the fault polarizing network **54** fails and the transistor **265** becomes non-conducting, the base of the transistor **266** will increase in potential, base current will flow and transistor **266** will conduct to shunt away any base drive to the transistor **216** from the terminals **208** and **238**. Similarly the transistors **267** and **268** are actuated in response to the presence or absence of the output signal from the 3ϕ fault polarizing network **56** to permit or shunt away the base drive signal to the transistor **216** from the terminals **220** and **240**.

The amplifying network **8** as discussed above is provided with three sets of input terminals **10**, **12** and **14**. The lower terminal of each of the sets **10**, **12** and **14** is connected through a current limiting resistor **276** to the base of a transistor **278** while the upper ones of each of the sets of terminals **10**, **12** and **14** is connected to the emitter. Emitter-collector potential is applied to the transistor **278** from a suitable direct current source connected between the positive and negative buses **280** and **282**. A diode **284** is connected between the emitter of the transistor **278** and the bus **280**. A resistor **286** is connected between the collector of the transistor **278** and the negative bus **282**. The potential across the resistor **286** is used to energize an RC circuit consisting of resistor **294** and capacitor **298** connected in series circuit with each other and in shunt with the resistor **286**. The potential across capacitor **298** is used to energize a pulse transformer **288** through a Shockley type diode **292** and for this purpose the primary winding **290** of the transformer has one end connected to one terminal of the capacitor **298** and its other end connected through a Shockley type diode **292** to the other terminal of the capacitor. Reverse current is prevented from flowing through the diode **292** by means of a diode **296** connected in antiparallel therewith.

The secondary winding **300** of the transformer **288** is connected between the gate and cathode of a controlled rectifier **302** through a current limiting resistor **304**. The anode of the rectifier **302** is connected through a current limiting resistor **306** to the positive bus **280** and its cathode is connected through the trip coil **6** of the breaker **4** to the negative bus **282**. In order to limit the forward voltage across the controlled rectifier **302** it may be and preferably is shunted by a Zener type diode **308**. A capacitor **310** series connected with a current limiting resistor **312** is shunt connected with the relay **6** to permit a more rapid buildup of current through the controlled rectifier **302** than would occur through the inductive trip coil **6** by itself. This feature is shown and claimed in my copending application Ser. No. 422,297 filed Dec. 30, 1964 for Control Device.

The output connection of the actuating networks **18** and **20** are connected to the input circuits **12** and **14** respectively of the amplifying network **8** through time delaying devices **314** and **316**. These devices may take any desired form which will produce a time delay between the time of energization of its input and the energization of its output so that the actuation of the amplifying network **8** and thereby the trip coil **6** may be delayed for first and second predetermined time intervals so that the zone **2** and zone **3** controls operate as back up devices in accordance with accepted relaying practice. The first time interval is preferably of lesser duration than the second time interval. An illustration of the use of back up apparatus may be found in my said Patent No. 2,973,460 as well as in protective relaying texts.

It is believed that the remainder of the details of construction may best be understood from a description of the operation of the apparatus which is as follows: The vector diagrams of FIGS. 3 and 3A vectorially illustrate the operation of the apparatus when the branch network **2** is unfaulted. As is more particularly brought out in FIG. 3A the phase of the operate signal E_{OC} on transformer **140** lags both of the voltages $E_{P\phi\phi C}$ and $E_{P3\phi C}$ supplied by the transformers **142** and **152**. The voltage potential transformer array **28** energizes the conductors **38**, **40** and **42** with voltages having phase angles and magnitudes proportional to the voltages found between the network conductors **32**, **34** and **36**. The voltage between the conductors **38** and **40** is applied to the winding **60** of the transformer **58** between the common tap **75** thereof, and a primary winding tap *a*, *b* or *c*. The voltage between the conductors **42** and **40** is applied to the winding 90 of the transformer 88 by connecting conductor 40 to the tap 78 and conductor 42 to the proper tap *a*, *b* or *c* of the winding 90 in a manner like that set forth in my said patent. The transformer 58 is energized with a potential proportional to that between the line conductors 32 and 34. The transformer 88 is energized by a potential proportional to that between the line conductors 34 and 36. In FIG. 3, the line conductors 32, 34 and 36 are represented by the reference characters A, B and C. The voltage which appears across the output winding 62 and the common portion of the winding 60 is represented by the vector E_{BA} and that which appears across the winding 92 and the common portion of the winding 90 is represented by the vector E_{CB}.

The output voltages which appear across the output terminals 74 and 76 of the logic networks 22, 24 and 26 are phase shifted with respect to the E_{BA} and E_{CB} vectors by an amount as determined by the compensators or summing devices 72. The device 72 is energized by the line current flowing in the conductors 32 and 34 and is represented by the vectors I_A and $-I_B$. These two vectors add together to provide a summed quantity I_{A-B}. The potential across the winding 70 developed by the quantity I_{A-B} is phase shifted as determined by the phase shifting network 86 to provide an output compensated quantity which is represented by the vector V_{C1}. This summed quantity is added to the output quantity of the transformer 58 to provide a voltage between the output terminals which is represented by the vector E_O. This output voltage is applied to the primary winding of the transformer 140 of the fault operate circuit 158. Due to the presence of the, diagrammatically illustrated, back-to-back Zener diodes 148, the magnitude of the voltage applied to the primary winding of the transformer is limited in magnitude of that a substantially square wave of voltage is applied. The magnitude of this voltage is so related to its frequency and with respect to the core of the transformer that the transformer 140 does not saturate and produces an equivalent square wave output voltage at its secondary winding 144. The phase of this output is represented in the vector diagram of FIG. 3A by the voltage vector E_{OC}.

The voltage added by the compensator or summing device 96 is derived from the vector sum of the currents flowing in the conductors 34 and 36 represented by the vectors I_C and $-I_B$. These quantities are vectorially added together and phase shifted by the network 102 to provide a summed quantity V_{C2}. This quantity adds to the quantity at the point C of the vector diagram to provide a quantity at terminals 76 to 106 which is represented by the vector $E_{P\phi\phi}$ in FIG. 3. This quantity is applied to the primary winding of the transformer 142, and is clipped by the diagrammatically illustrated back-to-back Zener diodes 150 to provide a square wave of a phase illustrated in vector diagram FIG. 3A by the vector quantity $E_{P\phi\phi C}$.

The three-phase polarizing signal network 56 is energized by the voltage appearing between the conductors 38 and 40 which is representative of the voltage between the conductors 32 and 34 and represented in the vector diagram of FIG. 3 by the voltage E_{BA}. This voltage is phase shifted by the network 56 to provide a voltage at its output terminals 132 and 134 which is phase shifted to lead the voltage E_{BA}. This quantity is represented in FIG. 3 by the voltage vector $E_{P3\phi}$. This voltage is clipped by the diagrammatically represented back-to-back Zener diodes 156 and the transformer 152 is energized by a substantially square wave which is phased 90° leading with respect to the voltage E_{BA}. The phase of this quantity is represented in FIG. 3A by the vector $E_{P3\phi C}$. FIG. 3A shows that each of the polarizing voltages $E_{P3\phi C}$ and $E_{P\phi\phi C}$ leads the operating voltage E_{OC} during normal operation of the network branch 2 by an angle which is less than 180°. With this phasing, the transistors 192 and 194 are rendered conducting when the polarizing voltages are maintaining the controlled rectifiers 246–252 and 250–254, respectively ready to conduct. Therefore, as soon as the lagging operating voltage E_{OC} causes the transistors 192 and 194 to conduct, the voltage drop between the terminals 208–220 and 238–240 and the negative bus 176 is less than the critical or breakover voltage of the Zener diode 214 and no base current will be supplied to cause the transistor 216 to conduct. Since the transistor 216 does not conduct, there is no drop across the resistor 226 and both of the output terminals 228, 230 thereof remain at the same potential, the amplifying network 8 remains unactuated and the trip coil 6 remains deenergized. Should the potential E_{CB} between conductors 34 and 36 fail for any reason as for example due to a fault on network 1 closely adjacent the breaker 4, the voltage $E_{P\phi\phi C}$ would not be effective to render the controlled rectifiers 246 and 252 in readiness to conduct so that the potential of the terminals 208 and 238 would be elevated to supply a base drive to transistor 216 to actuate the network 8 to energize the trip coil 6 which results in an undesired tripping of the breaker 4.

This undesired tripping is prevented by the voltage detecting circuit 166. When the transformer 142 becomes deenergized, the base drive for the transistor 265 terminates and this transistor 265 becomes non-conducting. This results in an increase in the potential of the base of the transistor 266 whereby base current flows and the transistor 266 conducts. This conduction of the transistor 266 connects the terminals 208 and 238 to the negative bus 176 through the diodes 210 and 242 thereby preventing base current flow from these terminals to the transistor 216. Similarly should the voltage $E_{P3\phi C}$ fail for any reasons, the transistor 267 will fail to conduct whereby the transistor 268 will conduct to connect the terminals 200 and 240 to the negative bus 176 and thereby prevent base current flow therefrom to the transistor 216 and undesired tripping of the breaker 4.

FIG. 4, shows vectorially the conditions which occur when the lines 32 and 34 in the branch network 2 become faulted within the reach of the zone 1 equipment. When such a fault occurs, the potential E_{AB} decreases in magnitude depending upon the distance from the equipment to the fault location. Such decrease is assumed to be the magnitude $E_{B'A'}$. Since the lines 32 and 34 are faulted together, the current flowing in conductor 32 is identical to that in conductor 34 except that the direction of the two currents is reversed. This fault current is represented in the vector diagram by the vectors I_A and $-I_B$. Since substantially no load current flows in the faulted lines 32 and 34 the phase angle of the current is substantially that of the impedance of the branch network 2. The phase shifting network 86 is adjusted so that the phase of the compensating quantity V_{C1} is 180° out of phase with the voltage $E_{B'A'}$. The high volts per turn of the windings of the transformer 72 provides a compensating quantity V_{C1} which is substantially greater than the voltage $E_{B'A'}$. The resulting potential E_O at the terminals 74 and 76 is opposite in phase substantially 180° out of phase with the voltage $E_{B'A'}$.

A voltage V_{C2} derived primarily from the $-I_B$ current since the current in the conductor 36 is of so small magnitude with respect to the current in the conductor 34. This current $-I_B$ is represented by the vector $-I_B$ extending from the point C in FIG. 4. The phase shift imparted by the phase shifting network 102, which is preferably the phase angle of the branch network 2 phases the voltage V_{C2} due to the current $-I_B$, which is added by the winding 94 to the output voltage of the transformers 88 to provide an output quantity $E_{P\phi\phi}$ between the terminals 108 and 76. This voltage $E_{P\phi\phi}$ is applied across the primary winding of the transformer 142 and Zener diodes 150. The phase angle of the output voltage of this transformer winding 146 is represented in FIG. 4A by the vector $E_{P\phi\phi C}$ and lags the phase of the operate voltage E_{OC} by an angle somewhat less than 180°. With this phasing of the vectors E_{OC} and $E_{P\phi\phi C}$, the transistors **192** and **194** will be rendered conducting prior to the rendering of the controlled rectifiers **246** and **250** conducting whereby base current will flow from the positive bus **174** through the transistors **192** and **194** and the Zener diode **214** to the transistor **216**. When so controlled, the transistor **216** conducts to establish a voltage across the resistor or voltage establishing impedance **226**.

The terminals **228** and **230** are connected between the upper and lower terminals respectively of the input **10**, so that base current flows through the transistor **278** which thereupon conducts to energize the voltage establishing resistor or impedance **286**. The voltage established by the impedance **286** with the transistor **278** conducting is sufficient to breakover the four layer device **292** and cause the primary winding **290** of the transformer **288** to be energized. The potential induced in the winding **300** causes gate current flow and renders the control rectifier **302** conducting. This causes an energizing current to the trip coil **6** which thereupon releases the breaker trip and the circuit breaker **4** opens to disconnect the network branch **2** from the network **1**.

In order to prevent any subsequent conduction of the controlled rectifiers **246–252** and **250–254**, the gate signals thereto are shunted by the transistors **260** and **264** respectively of the restraint squelch circuit **164**. When the transistor **192** conducts, it energizes the terminal **202**. This causes base current to flow base to emitter in the transistor **260** to thereby turn on the transistor **260** and effectively connect the gates of the controlled rectifiers **246** and **252** to the negative bus **176** to which the rectifier cathodes are connected. Therefore when the upper terminals of the windings **146** and **154** become positive, the current caused to flow thereby flows to the center terminal of the windings **146** and **154** through the transistor **260** rather than through the gate circuits of the controlled rectifiers **246** and **252** as would otherwise occur. The transistor **264** is similarly rendered conducting as a consequence of the conduction of the transistor **194** to shunt the gate current from the controlled rectifiers **250** and **254** to prevent their being rendered nonconducting when the lower end terminals of the windings **146** and **154** become positive with respect to their midtaps.

When the breaker **4** opens the contacts "*4a*" thereof will open the circuit through the rectifier **302**. The opening of the breaker **4** disconnects the network branch from the network **1** and interrupts the fault current. The logic network **22** will no longer indicate a faulted branch **2** and the trip coil actuating network **16** will become deenergized.

Let us now suppose that the fault between the conductors **32** and **34** was not located intermediate the breaker **4** and the next subsequent breaker but was located beyond the next subsequent breaker or in zone **2**. In such event, and assuming only fault current flows in the conductors **32** and **34** the magnitude of the currents I_A and $-I_B$ as illustrated in FIG. 4 would be sufficiently small so that the summed quantity V_{C1} would be less than the voltage $E_{B'C'}$ which voltage, under these conditions, would be greater. Vectorially the points B' and A' would be further apart and nearer their respective unfaulted voltage positions B and A, respectively. The direction of the output vector E_O would be reversed as would that of the vector E_{OC}. The polarizing vector $E_{P\phi\phi C}$ would then lead the operate vector E_{OC} with the results that the controlled rectifier **246** and **250** would connect the terminals **208** and **238** to the negative bus **176** and no base current would flow to the transistor **216**. The breaker would not be unwantedly opened. The zone **2** apparatus, however, has the terminal **64** connected to the "*b*" tap of the winding **60**. This in effect reduces the magnitude of the voltages E_{BA} and E_{CB} with respect to the magnitude of the quantities V_{C1} and V_{C2}. Therefore the magnitude $E_{B'A'}$ of the zone **2** fault is sufficiently reduced in magnitude relative to the quantity V_{C1} such that the operate vector E_{OC}

will remain in the direction as shown in FIG. 4A. Compensation may also be made by the adjustable windings of the compensators **72** and **96**.

In zone **3**, the terminals **64** and **68** are connected to the outer end taps "*c*" of the windings **60** and **90** and/or the adjustment of the windings **82**, **84**, **98** and **100** may be altered to provide for the still further reach of the zone **3** apparatus.

The zone **2** and zone **3** apparatuses actuate the amplifying network **8** through time delay networks **314** and **316** while the zone **1** network **158** is instantaneous. Therefore even though the zone **2** and zone **3** networks **18** and **20** are actuated by a fault in zone **1**, they are ineffective to actuate the amplifying network **8**. If however, the fault is beyond that zone **1** balance point of the illustrated relay but is within its zone **2** (zone **1** of the relay at the next control station) and the zone **1** relay at the next station fails to open the breaker, then after the time delay of the network **314**, the faulted line network section will be disconnected by the illustrated breaker **4**.

The connection of the current windings **82**, **84**, **98** and **100** of the compensators or summing devices **72** and **96** to the conductors **44**, **46** and **48** are shown as being adjustable in order to correlate further the magnitude of the vectors I_A, I_B, and I_C with respect to the current in the conductors **32**, **34** and **36**. This adjusts the impedance balance points to which the distance logic networks **22**, **24** and **26** are responsive.

FIG. 5 shows the vector quantities which exist when a fault occurs between the conductors **34** and **36** within the first zone. In this event, the voltage E_{CB} collapses to the voltage $E_{C'B'}$, the current I_A is negligible with respect to the currents I_B and I_C. The current I_B is equal and opposite to the current I_C as indicated in the vector diagram. The compensating quantity is represented by the vector V_{C1} and the operate voltage applied to the terminals **74** and **76** is represented by the vector E_O. The currents I_C and $-I_B$ together with the phase shifting network **102** provide a compensating quantity V_{C2}, which is added to the potential $E_{C'B'}$ provides a polarizing voltage $E_{P\phi\phi}$ which is in phase with the voltage $E_{C'B'}$ and equal to the difference between the quantities represented by the vector $E_{C'B'}$ and the vector V_{C2}. This voltage is applied to the transformer **142** and appears at the winding **146** as a quantity represented by the vector $E_{P\phi\phi C}$ as shown in FIG. 5A. The voltage at the winding **144** of the transformer **140** is represented by the vector E_{OC}. The vector E_{OC} leads the polarizing vector $E_{P\phi\phi C}$ whereby the terminals **208**, **238** will be raised in potential to supply base current to and render the transistor **216** conducting. The voltage vector $E_{P3\phi C}$ which leads the vector E_{OC} by less than 180° will cause the controlled rectifiers **252** and **254** to conduct but this is of course without effect since conduction of the transistor **216** will occur due to the lagging of the fault polarizing signal $E_{P\phi\phi C}$.

FIG. 6 illustrates, vectorially, the operation of the apparatus upon the occurrence of a fault between conductors **32** and **36** within the first zone. In this event, current I_C and I_A are equal and opposite and current I_B is substantially zero. The operate voltage E_O and polarizing voltage $E_{P\phi\phi}$ are supplied to the transformers **140** and **142**. The output voltage of these transformers are illustrated in FIG. 6A as E_{OC} and $E_{P\phi\phi C}$ provide for operation of the transistor **216**. It will be noted that in the line **32** to line **36** fault, the angle of lead of the operate voltage with respect to the polarizing voltage is small. The restraint squelch circuit **164** prevents subsequent actuation of the controlled rectifiers **246** and **250** and a sufficient signal is provided to operate the amplifier **8** to trip the breaker **4**.

FIG. 7, illustrates vectorially the relationships which occur for a three-phase fault in which the conductors **32**, **34** and **36** are shorted together and provide the voltage triangle A', B' and C'. In the case of a three phase fault, all three line currents I_A, I_B and I_C are present as fault currents and each will be phased with respect to the three phase voltage which exists between the conductors **32**, **34** and **36** and a neutral voltage at phase angle determined by the impedance of the network branch **2**. The summed quantities I_{S1} and I_{S2} are phase shifted by the network **86** and **102** and appear as compensating quantities V_{C1} and V_{C2}. These compensating quantities are added to the corresponding phase voltage quantities A′, B′ and C′ and provide operate and polarizing voltages E_{OC}, $E_{P\phi\phi C}$ and $E_{P3\phi C}$ as illustrated in FIG. 7A. It will be obvious in this instance that the polarizing voltage $E_{P\phi\phi C}$ leads the operate voltage E_{OC}. However, the polarizing voltage $E_{P3\phi C}$ provided by the three-phase fault polarizing signal network **56**, is however, phased 90° ahead of the voltage $E_{B'A'}$ and is in lagging relation with respect to the voltage E_{OC} which enables the transistor **216** to be rendered conducting to actuate the amplifying network **8** for energization of the trip coil **6** and opening of the breaker **4** as above described.

While back-to-back Zener diodes **148**, **150** and **166** are illustrated, it will be apparent that anti-parallel arranged conventional diodes may be provided and enough thereof connected in series so that the forward drop in each direction is equal to the desired magnitude of voltage for application to the primary winding of the transformers **140**, **142** and **152**. It will be apparent that the magnitudes of the output voltages of the transformers **140**, **142** and **152** is not important providing they are sufficient to trigger the various semiconducting devices. It is the phasing of these quantities which acutally performs the controlling operation.

Although the invention has been described with reference to a single embodiment thereof, numerous modifications are possible and it is desired to cover all modifications falling within the spirit and scope of the invention.

What is claimed and is desired to be secured by United States Letters Patent is as follows:

1. In a relaying system for a three phase network, a first plurality of input terminals supplying a three phase electrical quantity which is proportional to the potential of a three phase network from which said first terminals are energized, a second plurality of input terminals supplying a three phase electrical quantity which is proportional to the current flowing in a three phase network from which said second terminals are energized, first and second and third pairs of output terminals, first and second compensators, each said compensator including input means and output means and effective to energize its said output means with a compensating vector quantity which is the vector sum of electrical quantities supplied to its said input means, each said compensator further including means to shift the phase of its said compensating vector quantity with respect to said vector sum of said electrical quantities supplied thereto, first circuit means connecting a first pair of said first input terminals to said first pair of output terminals and including said output means of said first compensator whereby said first pair of output terminals is energized by the vector sum of the said quantities which are supplied to said first circuit means by said first pair of input terminals and said first compensator, a second circuit means connecting a second pair of said first input terminals to said second pair of output terminals and including said output means of said second compensator whereby said second pair of output terminals are energized by the vector sum of the said quantities which are supplied to said second circuit means by said second pair of input terminals and said second compensator, a phase shifting circuit, a third circuit means connecting said first pair of input terminals to said third pair of output terminals and including said phase shifting circuit whereby the phase of the said quantity which is supplied to said third pair of output terminals may be phase shifted with respect to the phase of the said quantity supplied to said third circuit means from said first pair of input terminals, means connecting said input means of said first compensator to a first group of terminals of said second plurality of terminals to supply a first current compensating quantity to said first compensator which is representative of the difference between a first phase quantity and a second phase quantity of said three phase quantity supplied by said second plurality of input terminals, means connecting said input means of said second compensator to a second group of terminals of said second plurality of terminals to supply a second current compensating quantity to said second compensator which is representative of the difference between two phase quantities of said three phase quantity supplied by said second plurality of input terminals, and a phase sensitive control circuit connected to said pairs of output terminals and effective when the phase of said quantity of a predetermined pair of said output terminals is leading in phase relationship with the phase of either of said quantities of the other two of said pairs of said output terminals.

2. The combination of claim **1** in which both said plurality of input terminals are supplied from the same three phase network, said first pair of said first plurality of input terminals being energized by a first phase of said three phase network, each said groups having first and second pairs of terminals, a first pair of terminals of said first group of terminals being energized by said first phase of said three phase network, said predetermined pair of said output terminals being energized by said first phase of said three phase network, said second pair of said first plurality of input terminals being energized by a second phase of said three phase network a first pair of terminals of said second group of terminals being energized by said second phase of said three phase network, said second pairs of terminals of said first and second groups of terminals being energized by a third phase of said three phase network.

3. The combination of claim **2** in which the phase rotation of said network is phase first and phase third and phase second and in which the phase angle of said current quantities with respect to their respective voltage quantities of said first pair of terminals of said first and second groups of terminal groups is not greater than ninety degrees, said voltage quantities being derived from said first and second pairs of said first plurality of input terminals respectively.

4. In a relaying system for a three phase network having conductors, means adapted to be connected to said network to derive therefrom first and second electrical voltage originated quantities representing the voltages between a second and a first of said conductors and between a third and said second of said conductors, means adapted to be connected to said network to derive therefrom third and fourth and fifth current originated electrical quantities representing the current in said first and said second and said third conductors respectively, said current quantities being considered positive when the phase angle thereof relative to the voltages which causes said respective current quantity is not in excess of 90 degrees and negative when such phase angle is greater than 90 degrees, first and second and third control output circuits, first circuit means vectorially supplying to said first output circuit said first quantity and said third quantity and said fourth quantity, said fourth quantity being in the negative direction and said third quantity being in the positive direction, second circuit means vectorially supplying to said second output circuit and said second quantity and said fourth quantity and said fifth quantity, said fourth quantity being in the negative direction and said fifth quantity being in the positive direction, and third circuit means supplying a sixth electrical quantity to said third output circuit, said sixth quantity being representative of an alternating voltage of the same frequency as that of said network and phased to lead said first quantity.

5. In a relaying system for a three phase network having conductors, means adapted to be connected to said network to derive therefrom first and second electrical voltage originated quantities representing the voltages between a second and a first of said conductors and between a third of said conductors and said second conductor, means adapted to be connected to said network to derive therefrom third and fourth and fifth current originated electrical quantities representing the current in said first and said second and said third conductors respectively, said current originated quantities being considered positive when the phase angle thereof relative to the voltages which cause said respective current quantity is not in excess of 90 degrees and negative when such phase angle is greater than 90 degrees, first and second and third control output circuits, first circuit means vectorially supplying to said first output circuit said first quantity and said third quantity and said fourth quantity, said fourth quantity being in the negative direction and said third quantity being in the positive direction, second circuit means vectorially supplying to said second output circuit said second quantity and said fourth quantity and said fifth quantity, said fourth quantity being in the negative direction and said fifth quantity being in the positive direction, and third circuit means supplying said first quantity to said third output circuit, said third circuit means including said phase shifting means for shifting the phase of said first quantity which is supplied to said third output circuit in a direction to lead the phase of said first quantity which is supplied to said first circuit means.

6. The combination of claim **5** in which there are provided first and second and third transformers, each said transformer having a primary winding and a secondary winding, said first and second and third output circuits being individually connected across said primary windings of said first and said second and said third transformers respectively, and a plurality of impedance means, individual one of said impedance means being connected in shunt with an individual one of said windings of each of said transformers, each said impedance means being characterized by the part that it will maintain a substantially constant voltage of predetermined magnitude thereacross in either polarity when energized with a voltage having a magnitude in excess of said predetermined magnitude, said predetermined magnitude being substantially less than the magnitude of the output quantities of said output circuits, and said transformers being of the non-saturating type whereby substantially square output voltage waves are obtained from said secondary windings.

7. The combination of claim **6** in which there is provided at least one switching circuit, each said switching circuit comprising first and second and third switches and first and second impedance devices, each said switch having a main circuit and a control circuit, said first switch being of the continuous control type in which its said control circut is operable to initiate and terminate current flow through its said main circuit, said second and third switches being of the discontinuous control type in which their said control circuits merely control the initiation of current flow through their respective said main circuits and current therethrough is terminated by other means, each said switching circuit being arranged with its said first impedance device connected in series with and intermediate said main circuits of its said first and second switches and being arranged with its said second impedance device connected in series with an intermediate said main circuits of its said first and third switches, means individually connecting said control circuits of said first and said second and said third switches to said secondary windings of said first and said second and said third transformers respectively, a load circuit, and means connecting said load circuit in shunt circuit with at least one said main circuit of said second and said third switches.

8. In a relaying system for a three phase network having a normal phase rotation such that the first and second and third conductors thereof reach their maximum voltages in the order mentioned, potential means for association with said network for obtaining therefrom first and second potential derived electrical quantities representative of the first and third phase voltages of said network which appear between said second and first conductors and between said third and second conductors respectively, current means for association with said network for obtaining therefrom third and fourth and fifth current derived electrical quantities representative of the first and second and third phase currents which flow in said first and second and third conductors respectively, said current and potential quantities being considered as being in a positive direction when the phase of such quantities is the same as the phase of the corresponding current and voltage in said network when power flows through said network in a predetermined direction, said quantities being considered as being in a negative direction when the phase thereof is reversed from said positive quantity, first and second summing networks each said summing network having input and output connections and phase shifting means, each said summing network being effective to deliver to its said output connection an output quantity which has a phase angle determined by the vector sum of the electrical quantities supplied to its said input connections and the magnitude of phase shift of its said phase shifting means, means delivering to said input connection of said first summing network said first and third quantities in their said positive directions and said fourth quantity in its said negative direction, means delivering to said input connections of said second summing network said second and fourth quantities in their said positive directions and said fourth quantity in its said negative direction, each said phase shifting means being operable to phase shift the vector sum of the electrical quantities supplied to the said input connections of its respective said summing network by an angle equal to the impedance angle of said three phase network, a phase shifting apparatus having input terminals and output terminals and being operable to phase shift an electrical quantity applied to its input terminals by a desired angle, and means energizing said input terminals of said phase shifting apparatus by said first electrical quantity, said phase shifting apparatus being effective to phase shift said first quantity such that the quantity of its said output terminals leads the voltage of the first phase of said three phase network by substantially 90 degrees.

9. The combination of claim **8** in which there is provided a load controlling network characterized by the fact that it is actuated when the phase of a first of three alternating voltages applied thereto is leading in phase with respect to either of the second and third of said voltages and is ineffective when said first voltage lags both of said second and said third voltages, said circuit means energizing said load controlling network from said summing networks and said phase shifting apparatus, the output quantity of said first summing network being said first voltage.

10. The combination of claim **8** in which there is provided a pair of load controlling circuits, each said circuit including a phase responsive control means, each said phase responsive control means including first and second input connections and an output circuit and characterized by the fact that when the phase of a pulsating electrical quantity applied to its said first input connection is leading in phase with respect to the phase of a pulsating electrical quantity applied to its said second input connection its said output circuit is rendered effective and when the phase of a pulsating electrical quantity applied to its said second input connection is leading with respect to the phase of a pulsating electrical quantity applied to its said first input connection its said output circuit is held ineffective, means connecting said first input connection of each of said phase responsive control means to said output connection of said first summing network, means connecting said second input connection of a first of said phase responsive control means to said output connection of said second summing network, and means connecting said second input connection of the second of said phase responsive control means to said output terminals of said phase shifting apparatus.

11. In combination, a transmission line having first and second and third conductors energized from a polyphase alternating potential source for transmitting electrical energy in a predetermined direction, the energization of said conductors normally being such that a first voltage between said second and said first conductors may be represented by a positive first potential vector, that a second voltage between said third and said second conductors may be represented by a positive second potential vector lagging said first vector by 120 electrical degrees and that a third voltage between said first and said third conductors may be represented by a positive third potential vector lagging said second vector by 120 electrical degrees, the current in said first and second and third conductors being representable by positive fourth and fifth and sixth current vectors having a phase angle of not over ninety degrees from the said first and second and third vectors respectively when said energy is flowing in said predetermined direction, first and second and third pairs of control terminals, each said pair of control terminals having a first and second terminal, potential energized means operatively connected to said transmission line and deriving therefrom first and third alternating electrical quantities of a fixed phase angle with respect to said first and third vectors, said first and third quantities being in phase when the phase angle thereof is said fixed angle with respect to said first and third voltages respectively and being out-of-phase when the phase angle thereof is 180° from said fixed angle, current energized means deriving from said transmission line fourth and fifth and sixth alternating electrical quantities of a predetermined phase angle with respect to said fourth and fifth and sixth vectors respectively, said fourth and fifth and sixth quantities being in phase when the phase angle thereof with respect to said currents in said first and second and third conductors respectively is said predetermined angle and being out of phase when the phase angle thereby is 180° from said predetermined angle, first and second summing devices, each said summing device having first and second pairs of input terminals and first and second output terminals, and means for vectorially summing the alternating quantities applied to its said pairs of input terminals to produce a first summed quantity, each said summing device further having means including phase shifting apparatus for supplying said first summed quantity to its said output terminals as a compensating quantity phase shifted from the phase of said first summed quantity, first and second and third potential quantity terminals, means applying said first quantity between said second and said first potential quantity terminals and applying said third quantity between said third and said second potential quantity terminals whereby the angles between the vector which represent said potential quantities at said potential quantity terminals is the same as the angle between the vectors representing the voltages from which said first and third potential quantities are derived, circuit means connecting said first potential quantity terminal to a first terminal of said first pair of control terminals through said output terminals of said first summing device, circuit means connecting said second potential quantity terminal to the second terminal of said first pair of control terminals whereby said first pair of control terminals is energized with a first alternating control quantity which is the vector sum of said inphase component of said first quantity and said compensating quantity of said first summing device, means connecting said current energized means to said pairs of input terminals of said first summing device for energization of said first pair thereof with the inphase component of said fourth quantity and for energization of said second pair thereof with the out-of-phase component of said fifth quantity, circuit means connecting said second potential quantity terminal to a first terminal of said second pair of control terminals, circuit means connecting said third potential quantity terminal to the second terminal of said second pair of control terminals through said output terminals of said second summing device whereby said second pair of input terminals is energized with a second alternating control quantity which is the vector sum of said inphase component of said third quantity and said compensating quantity of said second summing device, means connecting said current energized means to said pairs of input terminals of said second summing device for energization of said first pair thereof with the inphase component of said sixth quantity and for energization of said second pair thereof with the out-of-phase component of said fifth quantity, circuit means connecting said first potential quantity to said third pair of control terminals and including phase shifting means for shifting the phase of the quantity at said third pair of control terminals such that the vector representation of said last named quantity when taken in a direction from a first to a second terminal of said third pair of control terminals is leading with respect to said first quantity, and breaker trip means connected to said pairs of control terminals, said trip means being rendered effective to trip a breaker whenever the phase of the quantity between said first and second terminals of said first pair of contact terminals is leading with respect to the quantity between said first and second terminals of at least one of said second and said third pairs of control terminals.

12. In a relaying system, a first input generating network having a first input connection and a second input connection and an output connection, said network including means to energize said output connection with an output electrical quantity in response to the application of electrical input quantities to said input connections and to phase said output quantity with respect to one of said input quantities as a function of the relative phasing of said input quantities, a second signal generating network having at least one input connection for energization with an input electrical quantity and an output connection, said second network including means to energize its said output connection with an output quantity of a phase determined at least in part by the said input quantity which is supplied to said input connection of said second network, a pair of output terminals, a pair of power supply terminals, a switching network connecting said pairs of terminals and having first and second operating conditions in which said supply terminals are effective to cause energization and de-energization of said output terminals respectively, means operatively connecting said switching network to said output connection of one of said generating networks for transferring said switching network from its said second to its said first condition in accordance with the phase of said output quantity of said one generating network, said switching network having a third operating condition in which said switching network is rendered ineffective to energize its said output terminals in response to said one generating network, and means operatively connecting said switching network to the other of said generating networks whereby said other network is effective to place said switching network in its said third condition.

13. The combination of claim 12 in which said switching network is rendered in its said third condition solely when the phase angle between said output quantities when taken with respect to a given one of said output quantities lies within a given phase quadrant.

14. In a relaying system, first and second signal generators, providing first and second pulsating electrical output quantities at first and second output connections respectively in response to the application of input quantities applied to said generators, said generators including means to phase the pulse of said output quantity of one of said generators in leading and lagging time relation

with respect to the other of said generators in response to a change in the relative phases of said input quantities, a pair of output terminals, a switching network connected to said terminals and having first and second input connections, means connecting said first input connection to said first output connection, means connecting said second input connection to said second output connection, said switching network including means to energize said output terminals solely when the phase of said output quantity of said one generator is phased in one of said time relations and ineffective to energize said output terminals when the phase of said output quantity of said one generator is phased in the other of said time relations.

15. The combination of claim **14** in which said switching network is provided with means energized in timed relation with said output terminals and effective to render said switching network ineffective to deenergize said output terminals throughout the pulse period of the leading one of said electrical quantities when said phase is in said one time relation.

16. The combination of claim **14** in which there is provided a normally conductive shunting circuit connected between said output terminals to prevent energization thereof by said switching network, and means responsive to the energized condition of said other generator.

17. In a relaying system, an operate signal generator, a polarizing signal generator, each said generator providing spaced pulse-like electrical output quantities in response to alternating electrical quantities supplied thereto, a pair of input terminals, a pair of output terminals, first and second and third electric switches each said switch having a main circuit and a control circuit for controlling at least the initiation of current flow through its said main circuit, first means interconnecting said input terminals and including in series connection said main circuit of said first switch and said load terminals, means connecting said control circuit of said first switch to said operate generator for rendering conductive said main circuit of said first switch by said output quantity of said operate generator, second means interconnecting said input terminals and including said main circuit of said second switch, means connecting said control circuit of said second switch to said polarizing generator for rendering conductive said main circuit of said second switch by said output quantity of said polarizing generator, said second means having an impedance which is sufficiently low whereby the voltage drop thereacross, when said main circuit of second switch is conducting, is insufficient to provide a useable potential across said load terminals when said main circuit of said second switch is conductive, a third means connected in shunt with said control circuit of said second switch and including said main circuit of said third switch whereby said polarizing generator is ineffective to energize said control circuit of said second switch when said main circuit of said third switch is conductive, and means connecting said control circuit of said third switch to said main circuit of said first switch whereby conduction of said main circuit of said first switch initiates conduction of said main circuit of said third switch.

18. In a relaying system, an operate signal generator, a polarizing signal generator, said signal generators having input means adapted to be energized by alternating input quantities, each said generator having output connections energized with an alternating output quantity as a consequence of the energization of its said input means, the phase relationship of said output quantities being determined by the phase relationship of said input quantities, first and second impedance devices connected to said operate and said polarizing generators respectively for energization by said output quantities, each said device having first and second end terminals and an intermediate terminal, a pair of input terminals, a pair of load terminals, circuit means connecting a first of said input terminals to a first of said output terminals a plurality of switches, each said switch having a main circuit and a control circuit, means connecting the second of said input terminals to the second of said output terminals and including said main circuits of a first and of a second of said switches, said main circuits of said first and second switches being connected in parallel, means connecting said second output terminal to said first output terminal and including said main circuits of a third and of a fourth of said switches, said main circuits of said third and of said fourth switches being connected in parallel, means connecting said control circuits of said first and and of said second switches between said intermediate terminal and said first end terminal and between said intermediate terminal and said second end terminal of said first impedance device respectively whereby said main circuits of said first and second switches are sequentially rendered conducting in alternate relationship by said operate generator, means connecting said control circuits of said third and of said fourth switches between said intermediate terminal and said first end terminal and between said intermediate terminal and said second end terminal of said second impedance device respectively whereby said main circuits of said third and fourth switches are sequentially rendered conducting in alternate relationship by said polarizing generator.

19. In a relaying system, an operate signal generator, a polarizing signal generator, said signal generators having input means adapted to be energized by alternating input quantities, each said generator having output connections energized with an alternating output quantity as a consequence of the energization of its said input means, the phase relationship of said output quantities being determined by the phase relationship of said input quantities, first and second impedance devices connected to said operate and said polarizing generators respectively for energization by said output quantities, each said device having first and second end terminals and an intermediate terminal, a pair of input terminals, a pair of load terminals, circuit means connecting a first of said input terminals to a first of said output terminals a plurality of switches, each said switch having a main circuit and a control circuit, means connecting the second of said input terminals to the second of said output terminals and including said main circuits of a first and of a second of said switches, said main circuits of said first and second switches being connected in parallel, means connecting said second output terminal to said first output terminal and including said main circuits of a third and of a fourth of said switches, said main circuits of said third and of said fourth switches being connected in parallel, means connecting said control circuits of said first and of said second switches between said intermediate terminal and said first end terminal and between said intermediate terminal and said second end terminal of said first impedance device respectively whereby said main circuits of said first and second switches are sequentially rendered conducting in alternate relationship by said operate generator, means connecting said control circuits of said third and of said fourth switches between said intermediate terminal and said first end terminal and between said intermediate terminal and said second end terminal of said second impedance device respectively whereby said main circuits of said third and fourth switches are sequentially rendered conducting in alternate relationship by said polarizing generator, means connected to said control circuits of said third and of said fourth switches and including said main circuits of a fifth and of a sixth of said switches, means connecting said control circuits of said fifth and of said sixth switches to said main circuits of said first and of said second switches respectively, said fifth and said sixth switches being effective as a consequence of the conduction of said main circuits of said first and of said second switch to render said polarizing generator ineffective to render conductive said main circuits of said third and of said fourth switches.

20. The combination of claim 19 in which said main circuit of a sixth of said switches is connected between said output terminals and said control circuit of said sixth switch is operatively connected to said polarizing generator, said main circuit of said sixth switch being normally conductive to prevent energization of said load terminals in the absence of an output signal from said polarizing generator and being rendered non-conductive by said output quantity of said polarizing generator.

21. In a network, first and second alternating polarity electrical quantity sources, a unidirectional directional potential source, a load, a plurality of electric valves, each said valve having a main circuit and a control circuit, first circuit means connecting said load to said unidirectional source and including said main circuit of a first of said valves, means connecting said control circuit of said first valve to said first alternating source whereby said main circuit of said first valve is periodically rendered conducting in timed relation to the alternations of said alternating quantity of said first source, means connecting said main circuit of a second of said valves in series circuit with said main circuit of said first valve and in shunt with said load, means connecting said control circuit of said second valve to said second alternating source whereby said main circuit of said second valve is periodically rendered conducting in timed relation to the alternations of said alternating quantity of said second source, means connecting said main circuit of a third of said valves in said first circuit means, said third valve being effective in a first condition to render said first valve ineffective to energize said load and effective in a second condition to render said first and second valves effective to control the energization of said load, means connecting said control circuit of said third valve to said second source whereby said third valve is held in its said first condition in the absence of said electrical quantity of said second source and held in its said second condition in the presence of said electrical quantity of said second source, means limiting the current flow through said main circuit of said first valve.

22. The combination of claim 21 in which there is a fourth of said valves, means connecting said main circuit of said fourth valve to said control circuit of said second valve, said fourth valve being effective in a first condition to render said control circuit of said second valve effective to respond to said alternating quantity of said second source, said fourth valve being effective in a second condition to render said control circuit of said second valve ineffective to respond to said alternating quantity of said second source, and means connecting said control circuit of said fourth valve to said first valve whereby said fourth valve is transferred from its said first to its said second condition in timed relation to the rendering of said main circuit of said first valve conductive.

23. The combination of claim 21 in which there is a fourth of said valves, means connecting said main circuit of said fourth valve to said control circuit of said second valve, said fourth valve being effective in a first condition to render said control circuit of said second valve effective to respond to said alternating quantity of said second source, said fourth valve being effective in a second condition to render said control circuit of said second valve ineffective to respond to said alternating quantity of said second source, and means connecting said control circuit of said fourth valve to said first valve whereby said fourth valve is transferred from its said first to its said second condition in timed relation to the rendering said main circuit of said first valve conductive, at least said first valve being of the continuous control type in which current flow through its said main circuit is interrupted as well as initiated by its said control circuit, at least said second valve being of the discontinuous control type in which the initiation of current flow through its said main circuit is controlled by its said control circuit but its said control circuit is ineffective to interrupt current flow through its said main circuit.

24. In a network, first and second alternating polarity electrical quantity sources, a unidirectional directional potential source, a load, a plurality of electric valves, each said valve having a main circuit and a control circuit, first circuit means connecting said load to said unidirectional source and including said main circuit of a first of said valves, means connecting said control circuit of said first valve to said first alternating source whereby said main circuit of said first valve is periodically rendered conducting in timed relation to the alternations of said alternating quantity of said first source, means connecting said main circuit of a second of said valves in series circuit with said main circuit of said first valve and in shunt with said load, means connecting said control circuit of said second valve to said second alternating source whereby said main circuit of said second valve is periodically rendered conducting in timed relation to the alternations of said alternating quantity of said second source, a third of said valves, means connecting said main circuit of said third valve to said control circuit of said second valve, said third valve being effective in a first condition to render said control circuit of said second valve effective to respond to said alternating quantity of said second source, said third valve being effective in a second condition to render said control circuit of said second valve ineffective to respond to said alternating quantity of said second source, and means connecting said control circuit of said third valve to said first valve whereby said third valve is transferred from its said first to its said second condition in timed relation to the rendering of said main circuit of said first valve conductive.

25. In an apparatus for use in protecting a three phase electrical transmission line, first and second and third potential supplying terminals adapted to be engaged with a potential device respectively from the first and second and third line conductors of said transmission line and proportioned to the said line potentials first and second and third current supply circuits adapted to be energized with a current derived respectively from the first and second and third line conductors of said transmission line and proportioned to the said line currents, an operate signal generator having input terminals and output terminals and a first signal forming network interconnecting its said input terminals to its said output terminals, said signal network comprising a mutual inductance device having a first winding connected between one of said input terminals and one of said output terminals and additional winding means, said additional winding means being connected to said first and second current supply circuits to energize said inductance device with a current quantity equal to the difference in the current magnitudes in said first and said second current supply circuits, an electrical conducting path connecting the other of said input terminals to the other of said output terminals, a transformer having a first winding connected between said output terminals and a second winding having end terminals and an intermediate terminal, means connecting said input terminals of said generator to said first and said second potential supplying terminals, first and second switch devices each said device having a main circuit and a control circuit for initiating and terminating current flow through its associated said main circuit, a pair of direct potential energized buses, an output circuit, first and second impedance devices, each said impedance device having first and second terminals, means connecting said first terminal of said first impedance device to one of said buses and including said main circuit of said first valve, means connecting said first terminal, said second impedance device to said one bus and including said main circuit of said second valve, means connecting said second terminals of said impedance devices through said output circuit to the other of said buses, means connecting said control cir-

cuit of said first valve between said intermediate terminal and one of said end terminals and connecting said control circuit of said second valve between said intermediate terminal and the other of said end terminals whereby said first and second valves are rendered conducting in alternating relation, a first polarizing signal generator having a pair of input terminals connected to a pair of output terminals through a phase shifting circuit and a resonant circuit, said resonant circuit including capacitive and inductive reactance tuned to resonate at the frequency of said protected three phase line, means connecting said output terminals of said polarizing generator to said first and said second potential supplying terminals, a second transformer having a primary winding connected to said output terminals of said polarizing generator and a secondary winding having end terminals and an intermediate terminal, third and fourth switch devices, each said third and fourth switch devices being a main circuit and a control circuit for initiating current flow through its said main circuit, means connecting said control circuit of said third valve between said intermediate terminal and one of said end terminals of said secondary winding of said second transformer and connecting said control circuit of said fourth valve between said intermediate terminal and the other of said end terminals of said secondary winding of said second transformer, circuit means connecting said first terminal of said first impedance device to said other bus and including said main circuit of said third valve, and circuit means connecting said first terminal of said second impedance device to said other bus and including said main circuit of said fourth valve.

26. In an apparatus for use in protecting a three phase electrical transmission line, first and second and third potential supplying terminals adapted to be engaged with a potential device respectively from the first and second and third line conductors of said transmission line and proportioned to the said line potentials first and second and third current supply circuits adapted to be energized with a current derived respectively from the first and second and third line conductors of said transmission line and proportioned to the said line currents, an operate signal generator having input terminals and output terminals and a first signal forming network interconnecting its said input terminals to its said output terminals, said signal network comprising a mutual inductance device having a first winding connected between one of said input terminals and one of said output terminals and additional winding means, said additional winding means being connected to said first and second current supply circuits to energize said inductance device with a current quantity equal to the difference in the current magnitudes in said first and said second current supply circuits, an electrical conducting path connecting the other of said input terminals to the other of said output terminals, a transformer having a first winding connected between said output terminals and a second winding having end terminals and an intermediate terminal, means connecting said input terminals of said generator to said first and said second potential supplying terminals, first and second switch devices each said device having a main circuit and a control circuit for initiating and terminating current flow through its associated said main circuit, a pair of direct potential energized buses, an output circuit, first and second impedance devices, each said impedance device having first and second terminals, means connecting said first terminal of said first impedance device to one of said buses and including said main circuit of said first valve, means connecting said first terminal, said second impedance device to said one bus and including said main circuit of said second valve, means connecting said second terminals of said impedance devices through said output circuit to the other of said buses, means connecting said control circuit of said first valve between said intermediate terminal and one of said end terminals and connecting said control circuit of said second valve between

said intermediate terminal and the other of said end terminals whereby said first and second valves are rendered conducting in alternating relation, a first polarizing signal generator having a pair of input terminals connected to a pair of output terminals through a phase shifting circuit and a resonant circuit, said resonant circuit including capacitive and inductive reactance tuned to resonate at the frequency of said protected three phase line, means connecting said output terminals of said polarizing generator to said first and said second potential supplying terminals, a second transformer having a primary winding connected to said output terminals of said polarizing generator and a secondary winding having end terminals and an intermediate terminal, third and fourth switch devices, each said third and fourth switch devices being a main circuit and a control circuit for initiating current flow through its said main circuit, means connecting said control circuit of said third valve between said intermediate terminal and one of said end terminals of said secondary winding of said second transformer and connecting said control circuit of said fourth valve between said intermediate terminal and the other of said end terminals of said secondary winding of said second transformer, circuit means connecting said first terminal of said first impedance device to said other bus and including said main circuit of said third valve, and circuit means connecting said first terminal of said second impedance device to said other bus and including said main circuit of said fourth valve, a fifth value having a main circuit for initiating current flow through its said main circuit, circuit means connecting said main circuit of said fifth value in shunt with said output circuit, and circuit means connected to said contact circuit of said fifth valve and to a pair of said potential supplying terminals, said last named circuit means including means for maintaining said main circuit of said fifth valve nonconducting when said pair of potential supplying terminals are energized.

27. In an apparatus for use in protecting a three phase electrical transmission line, first and second and third potential supplying terminals adapted to be engaged with a potential device respectively from the first and second and third line conductors of said transmission line and proportioned to the said line potentials first and second and third current supply circuits adapted to be energized with a current derived respectively from the first and second and third line conductors of said transmission line and proportioned to the said line currents, an operate signal generator having input terminals and output terminals and a first signal forming network interconnecting its said input terminals to its said output terminals, said signal network comprising a mutual inductance device having a first winding connected between one of said input terminals and one of said output terminals and additional winding means, said additional winding means being connected to said first and second current supply circuits to energize said inductance device with a current quantity equal to the difference in the current magnitudes in said first and said second current supply circuits, an electrical conducting path connecting the other of said input terminals to the other of said output terminals, a transformer having a first winding connected between said output terminals and a second winding having end terminals and an intermediate terminal, means connecting said input terminals of said generator to said first and said second potential supplying terminals, first and second switch devices each said device having a main circuit and a control circuit for initiating and terminating current flow through its associated said main circuit, a pair of direct potential energized buses, an output circuit, first and second impedance devices, each said impedance device having first and second terminals, means connecting said first terminal of said first impedance device to one of said buses and including said main circuit of said first valve, means connecting said first terminal, said second impedance device to said one bus and including said main circuit of said second valve, means connecting said second terminals of said impedance devices through said output circuit to the other of said buses, means connecting said control circuit of said first valve between said intermediate terminal and one of said end terminals and connecting said control circuit of said second valve between said intermediate terminal and the other of said end terminals whereby said first and second valves are rendered conducting in alternating relation, a first polarizing signal generator having a pair of input terminals connected to a pair of output terminals through a phase shifting circuit and a resonant circuit, said resonant circuit including capacitive and inductive reactance tuned to resonate at the frequency of said protected three phase line, means connecting said output terminals of said polarizing generator to said first and second potential supplying terminals, a second transformer having a primary winding connected to said output terminals of said polarizing generator and a secondary winding having end terminals and an intermediate terminal, third and fourth switch devices, each said third and fourth switch devices being a main circuit and a control circuit for initiating current flow through its said main circuit, means connecting said control circuit of said third valve between said intermediate terminal and one of said end terminals of said secondary winding of said second transformer and connecting said control circuit of said fourth valve between said intermediate terminal and the other of said end terminals of said secondary winding of said second transformer, circuit means connecting said first terminal of said first impedance device to said other bus and including said main circuit of said third valve, and circuit means connecting said first terminal of said second impedance device to said other bus and including said main circuit of said fourth valve, a second polarizing generator having input terminals and output terminals and a second signal forming interconnecting its said input terminals to its said output terminals, said second signal forming networks comprising a second mutual inductance device having a first winding connected between one of said input terminals and one of said output terminals of said second polarizing generator and additional winding means, said additional winding means being connected to said second and said third current supplying circuits to energize said second mutual inductance device with a current quantity equal to the difference in the current magnitude in said second and said third current supply circuits, an electrical conducting path connecting the other of said input terminals of said second polarizing generator to the other of said output terminals of said second polarizing generator, a third transformer having a primary winding connected between said output terminals of said second polarizing generator and a secondary winding having end terminals and an intermediate terminal, a fifth and a sixth valve, each said fifth and said sixth valve having a main circuit and a contact circuit for initiating the flow of current through its said main circuit, circuit means connecting said second terminal of said first impedance to said other bus and including said main circuit of said fourth valve, circuit means connecting said second terminal of said second impedance to said other bus and including said main circuit of said fifth valve, means connecting said control circuit of said fourth valve between said intermediate terminal and one of said end terminals of said secondary winding of said third transformer, means connecting said control circuit of said sixth valve between said intermediate terminal and the other of said end terminals of said secondary winding of said third transformer.

28. In an apparatus for use in protecting a three phase electrical transmission line, first and second and third potential supplying terminals adapted to be engaged with a potential device respectively from the first and second and third line conductors of said transmission line and proportioned to the said line potentials first and second and third current supply circuits adapted to be energized with a current derived respectively from the first and second and third line conductors of said transmission line and proportioned to the said line currents, an operate signal generator having input terminals and output terminals and a first signal forming network interconnecting its said input terminals to its said output terminals, said signal network comprising a mutual inductance device having a first winding connected between one of said input terminals and one of said output terminals and additional winding means, said additional winding means being connected to said first and second current supply circuits to energize said inductance device with a current quantity equal to the difference in the current magnitudes in said first and said second current supply circuits, an electrical conducting path connecting the other of said input terminals to the other of said output terminals, a transformer having a first winding connected between said output terminals and a second winding having end terminals and an intermediate terminal, means connecting said input terminals of said generator to said first and said second potential supplying terminals, first and second switch devices each said device having a main circuit and a control circuit for initiating and terminating current flow through its associated said main circuit, a pair of direct potential energized buses, an output circuit, first and second impedance devices, each said impedance device having first and second terminals, means connecting said first terminal of said first impedance device to one of said buses and including said main circuit of said first valve, means connecting said first terminal, said second impedance device to said one bus and including said main circuit of said second valve, means connecting said second terminals of said impedance devices through said output circuit to the other of said buses, means connecting said control circuit of said first valve between said intermediate terminal and one of said end terminals and connecting said control circuit of said second valve between said intermediate terminal and the other of said end terminals whereby said first and second valves are rendered conducting in alternating relating a first polarizing signal generator having a pair of input terminals connected to a pair of output terminals through a phase shifting circuit and a resonant circuit, said resonant circuit including capacitive and inductive reactance tuned to resonate at the frequency of said protected three phase line, means connecting said output terminals of said polarizing generator to said first and said second potential supplying terminals, a second transformer having a primary winding connected to said output terminals of said polarizing generator and a secondary winding having end terminals and an intermediate terminal, third and fourth switch devices, each said third and fourth switch devices being a main circuit and a control circuit for initiating current flow through its said main circuit, means connecting said control circuit of said third valve between said intermediate terminal and one of said end terminals of said secondary winding of said second transformer and connecting said control circuit of said fourth valve between said intermediate terminal and the other of said end terminals of said secondary winding of said second transformer, circuit means connecting said first terminal of said first impedance device to said other bus and including said main circuit of said third valve, and circuit means connecting said first terminal of said second impedance device to said other bus and including said main circuit of said fourth valve, a second polarizing generator having input terminals and output terminals and a second signal forming interconnecting its said input terminals to its said output terminals, said second signal forming networks comprising a second mutual inductance device having a first winding connected between one of said input terminals and one of said output terminals of said second polarizing generator and additional winding means, said additional winding means being connected to said second and said third current supplying circuits to energize said second mutual inductance device with a current quantity equal to the difference in the current magnitude in said second and said third current supply circuits, an electrical conducting path connecting the other of said input terminals of said second polarizing generator to the other of said output terminals of said second polarizing generator, a third transformer having a primary winding connected between said output terminals of said second polarizing generator and a secondary winding having end terminals and an intermediate terminal, a fifth and a sixth valve, each said fifth and said sixth valve having a main circuit and a contact circuit for initiating the flow of current through its said main circuit, circuit means connecting said second terminal of said first impedance to said other bus and including said main circuit of said fourth valve, circuit means connecting said second terminal of said second impedance to said other bus and including said main circuit of said fifth valve, means connecting said control circuit of said fourth valve between said intermediate terminal and one of said end terminals of said secondary winding of said third transformer, means connecting said control circuit of said sixth valve between said intermediate terminal and the other of said end terminals of said secondary winding of said third transformer, a seventh and an eighth valve, each said seventh and said eighth valve having a main circuit and a contact circuit for initiating the flow of current through its said main circuit, circuit means connecting said main circuit of said seventh valve in shunt with said main circuit of said third valve and said main circuit of said eighth valve in shunt with said main circuit of said fourth valve, circuit means connecting said control circuit of said seventh valve in circuit with said main circuit of said first valve and said control circuit of said eighth valve in circuit with said main circuit of said second valve.

29. In an apparatus for use in protecting a three phase electrical transmission line, first and second and third potential supplying terminals adapted to be engaged with a potential device respectively from the first and second and third line conductors of said transmission line and proportioned to the said line potentials first and second and third current supply circuits adapted to be energized with a current derived respectively from the first and second and third line conductors of said transmission line and proportioned to the said line currents, an operate signal generator having input terminals and output terminals and a first signal forming network interconnecting its said input terminals to its said output terminals, said signal network comprising a mutual inductance device having a first winding connected between one of said input terminals and one of said output terminals and additional winding means, said additional winding means being connected to said first and second current supply circuits to energize said inductance device with a current quantity equal to the difference in the current magnitudes in said first and said second current supply circuits, an electrical conducting path connecting the other of said input terminals to the other of said output terminals, a transformer having a first winding connected between said output terminals and a second winding having end terminals and an intermediate terminal, means connecting said input terminals of said generator to said first and said second potential supplying terminals, first and second switch devices each said device having a main circuit and a control circuit for initiating and terminating current flow through its associated said main circuit, a pair of direct potential energized buses, an output circuit, first and second impedance devices, each said impedance device having first and second terminals, means connecting said first terminal of said first impedance device to one of said buses and including said main circuit of said first value, means connecting said first terminal, said second impedance device to said one bus and including said main circuit of said second value, means connecting said second terminals of said impedance devices through said output circuit to the other of said buses, means connecting said control circuit of said first valve between said intermediate terminal and one of said end terminals and connecting said control circuit of said second valve between said intermediate terminal and the other of said end terminals whereby said first and second valves are rendered conducting in alternating relation, a first polarizing signal generator having a pair of input terminals connected to a pair of output terminals through a phase shifting circuit and a resonant circuit, said resonant circuit including capacitive and inductive reactance tuned to resonate at the frequency of said protected three phase line, means connecting said output terminals of said polarizing generator to said first and said second potential supplying terminals, a second transformer having a primary winding connected to said output terminals of said polarizing generator and a secondary winding having end terminals and an intermediate terminal, third and fourth switch devices, each said third and fourth switch devices being a main circuit and a control circuit for initiating current flow through its said main circuit, means connecting said control circuit of said third valve between said intermediate terminal and one of said end terminals of said secondary winding of said second transformer and connecting said control circuit of said fourth valve between said intermediate terminal and the other of said end terminals of said secondary winding of said second transformer, circuit means connecting said first terminal of said first impedance device to said other bus and including said main circuit of said third valve, and circuit means connecting said first terminal of said second impedance device to said other bus and including said main circuit of said fourth valve, a second polarizing generator having input terminals and output terminals and a second signal forming interconnecting its said input terminals to its said output terminals, said second signal forming networks comprising a second mutual inductance device having a first winding connected between one of said input terminals and one of said output terminals of said second polarizing generator and additional winding means, said additional winding means being connected to said second and said third current supplying circuits to energize said second mutual inductance device with a current quantity equal to the difference in the current magnitude in said second and said third current supply circuits, an electrical conducting path connecting the other of said input terminals of said second polarizing generator to the other of said output terminals of said second polarizing generator, a third transformer having a primary winding connected between said output terminals of said second polarizing generator and a secondary winding having end terminals and an intermediate terminal, a fifth and a sixth valve, each said fifth and said sixth valve having a main circuit and a contact circuit for initiating the flow of current through its said main circuit, circuit means connecting said second terminal of said first impedance to said other bus and including said main circuit of said fourth valve, circuit means connecting said second terminal of said second impedance to said other bus and including said main circuit of said fifth valve, means connecting said control circuit of said fourth valve between said intermediate terminal and one of said end terminals of said secondary winding of said third transformer, means connecting said control circuit of said sixth valve between said intermediate terminal and the other of said end terminals of said secondary winding of said third transformer, a seventh and an eighth valve, each said seventh and said eighth valve having a main circuit and a contact circuit for initiating the flow of current through its said main circuit, circuit means connecting said main circuit of said seventh valve in shunt with said main circuit of said third valve and said main circuit of said eighth valve in shunt with said main circuit of said fourth valve, circuit means connecting said control circuit of said seventh valve in circuit with said main circuit of said first valve and said control circuit of said eighth valve in circuit with said main circuit of said second valve, a ninth valve having a main circuit and a control circuit for initiating current flow through its said main circuit, circuit means connecting said main circuit of said ninth valve in shunt with said output circuit, and circuit means connected to said control circuit of said ninth valve and to a pair of said potential supplying terminals, said last named circuit means including means for maintaining said main circuit of said ninth valve nonconducting when said pair of potential supplying terminals are energized.

References Cited

UNITED STATES PATENTS

3,144,586	8/1964	Gambale	317—36
3,192,442	6/1965	Warrinton	317—36
3,201,651	8/1965	Calhoun	317—36
3,303,390	2/1967	Sonnemann	317—36

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