United States Patent

[11] 3,609,523

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[21] Appl. No. **812,770**
[22] Filed **Apr. 2, 1969**
[45] Patented **Sept. 28, 1971**
[73] Assignee **Wayne Electronic Products Company**

[54] **AUTOMATIC TEST APPARATUS FOR PHASE COMPARISON PROTECTIVE RELAY SYSTEMS AND THE LIKE**
13 Claims, 10 Drawing Figs.

[52] **U.S. Cl.** **324/28,** 317/28
[51] **Int. Cl.** **G01r 31/02**
[50] **Field of Search** ..... 324/28; 317/9 R, 28.2, 28

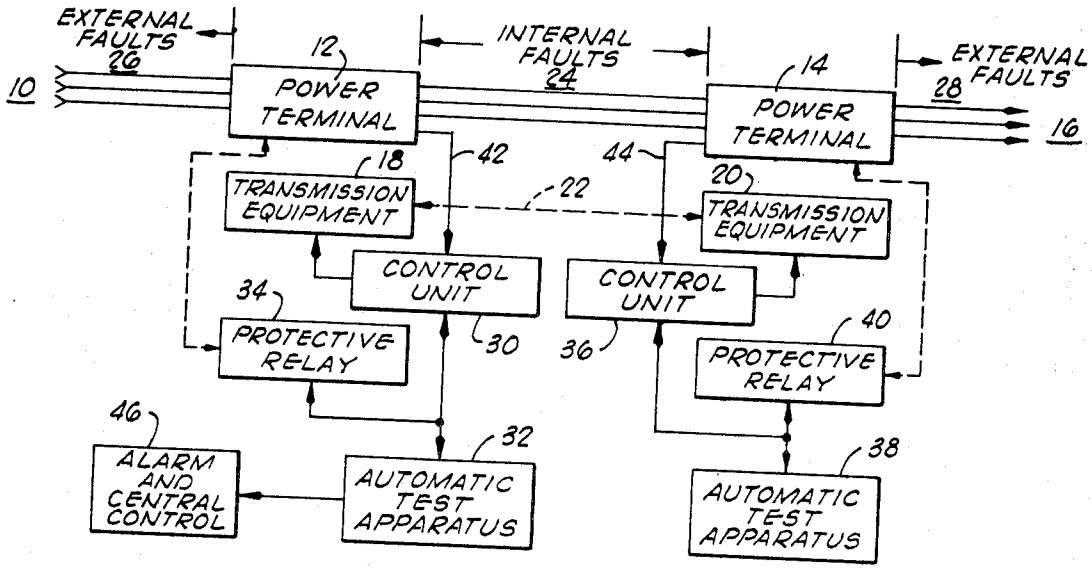
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ABSTRACT: Apparatus for automatically testing protective relay system as utilized with high voltage transmission lines, the apparatus consisting of a master control unit, at a first terminal working in conjunction with one or two slave control units at adjacent terminal stations. Each of the master and slave control units are controlled through a cycle of actuation by a synchronous timer means such that a programmed series of switch closures performs a test of associated transmission and reception equipment and the respective protective relay devices to transmit starting signal, ring back, internal and external simulated faults and a selected security code. Each test control unit utilizes a time-controlled program switch which is synchronously operable to effect various test and verify operations in the control unit.



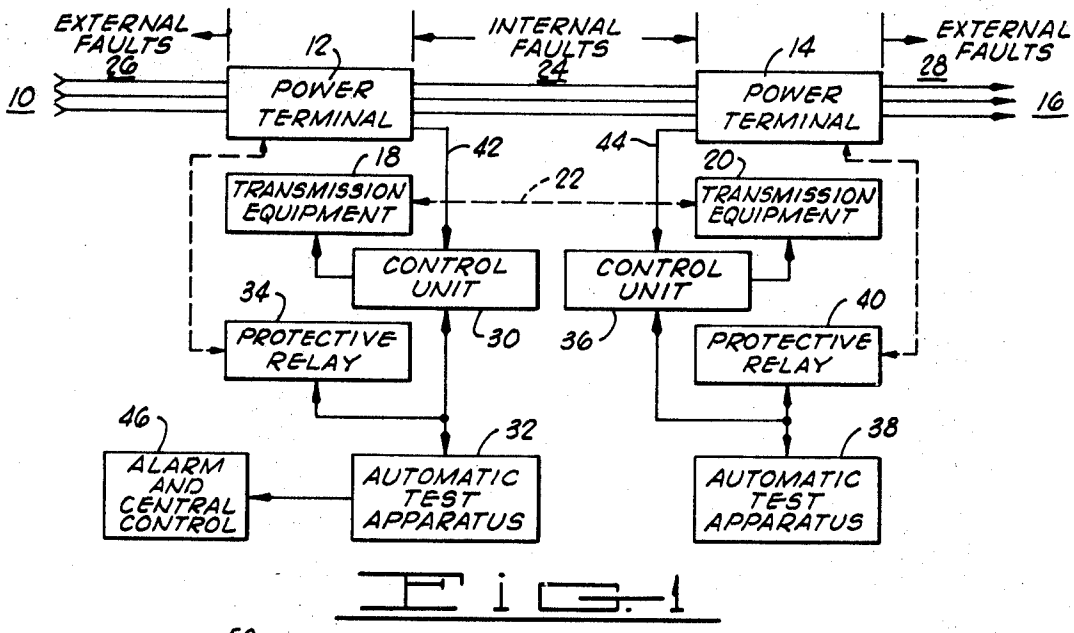


Fig. 1

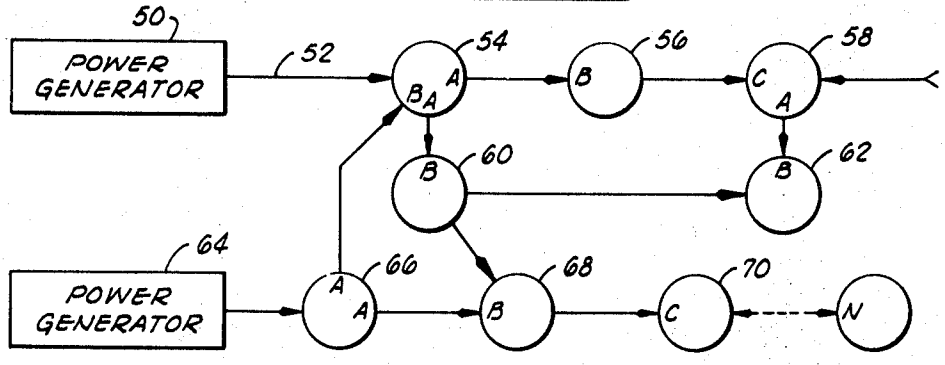


Fig. 2

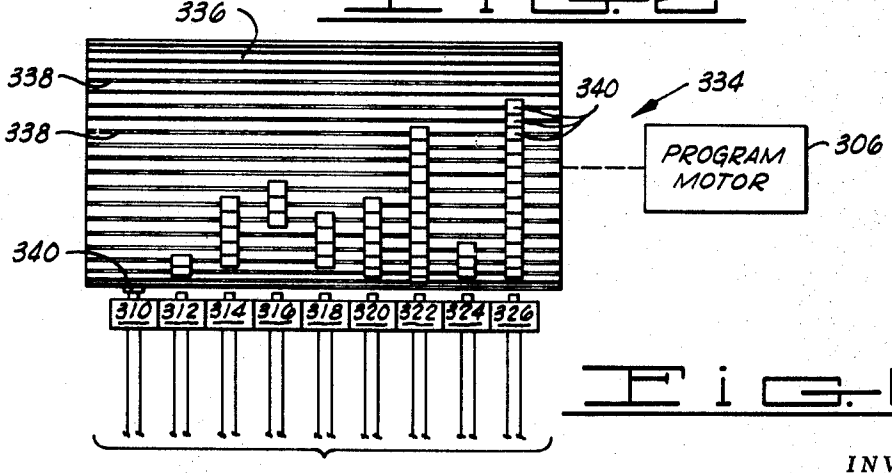


Fig. 6

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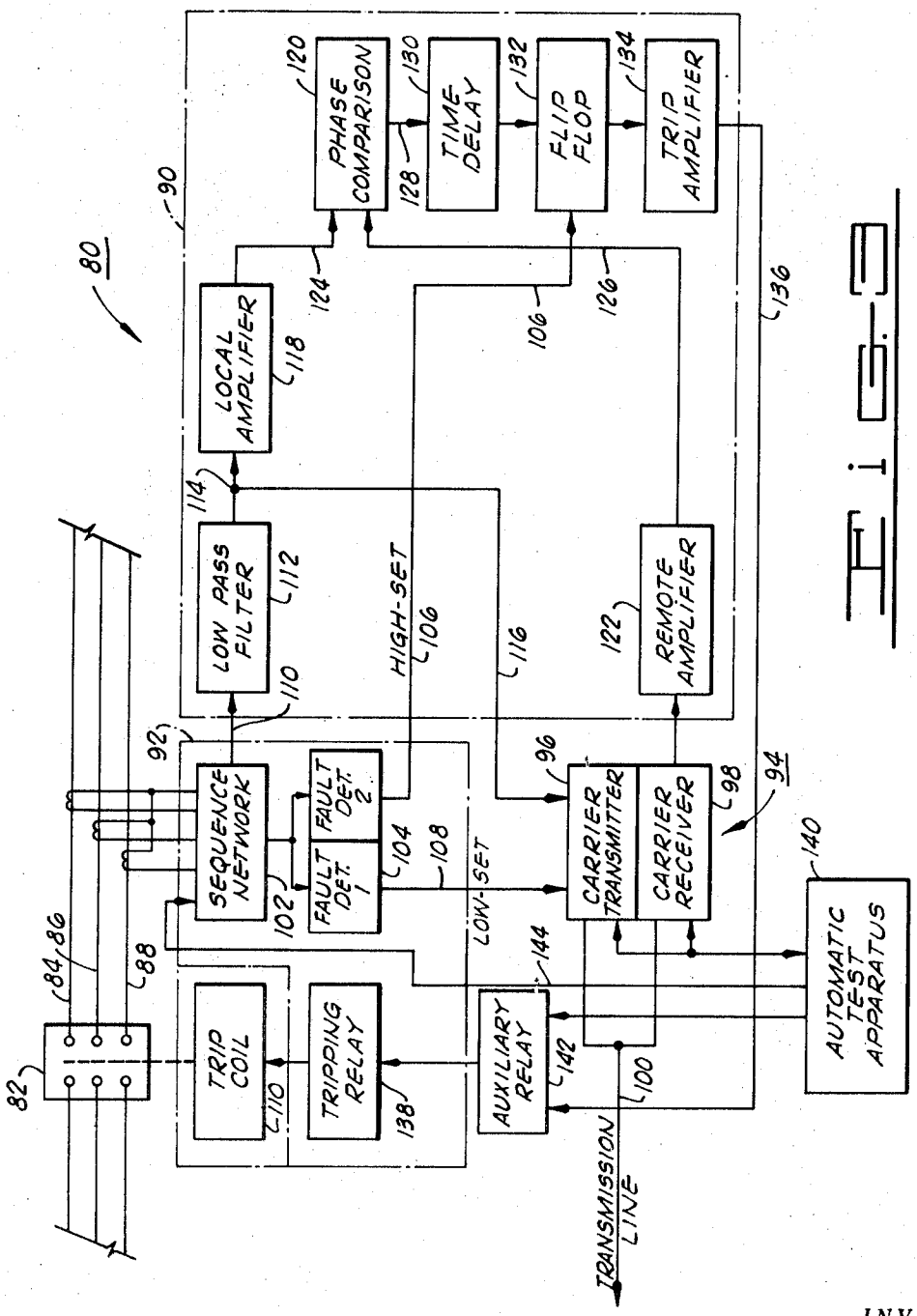


Fig. 3

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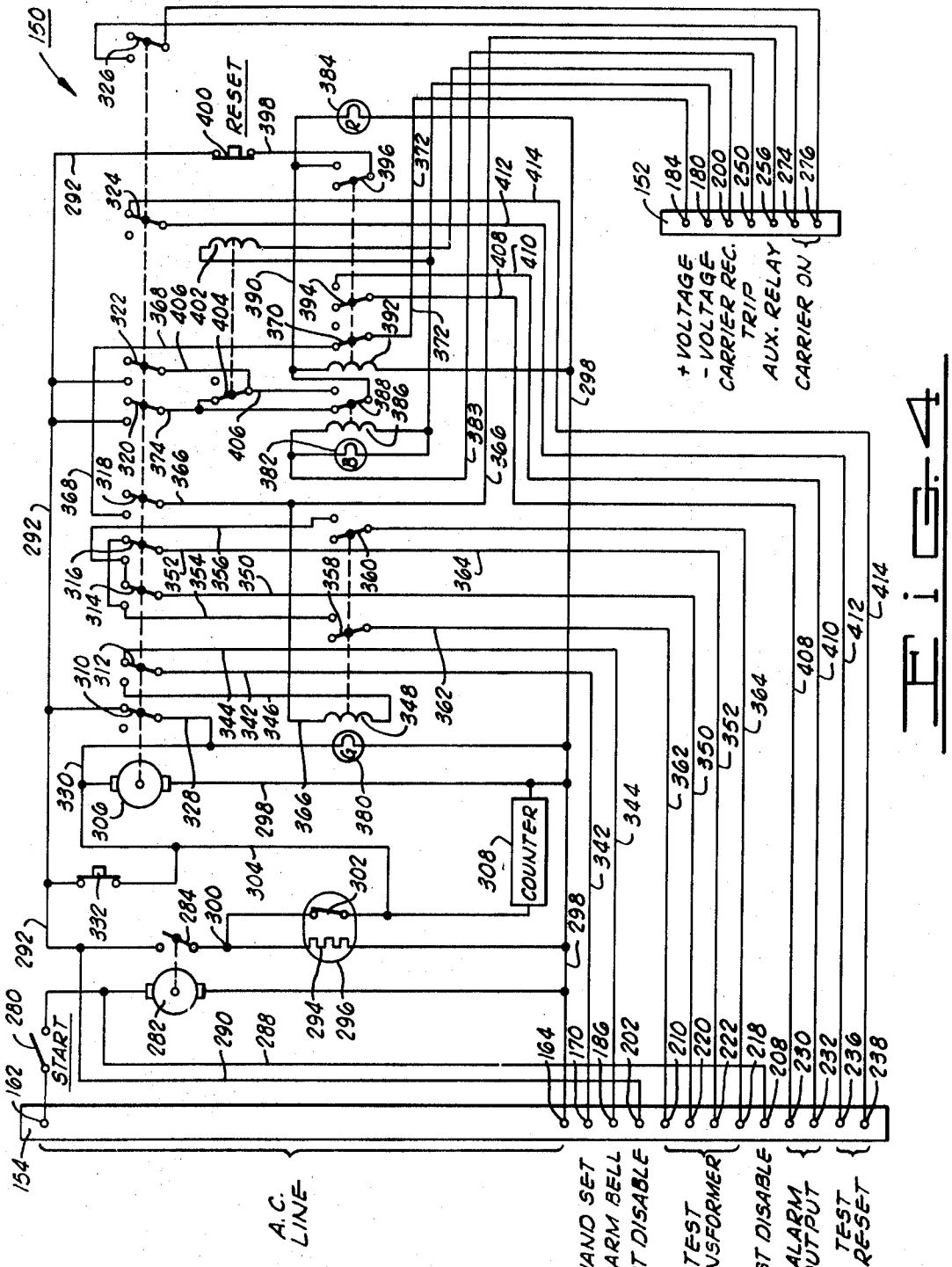


Fig. 4

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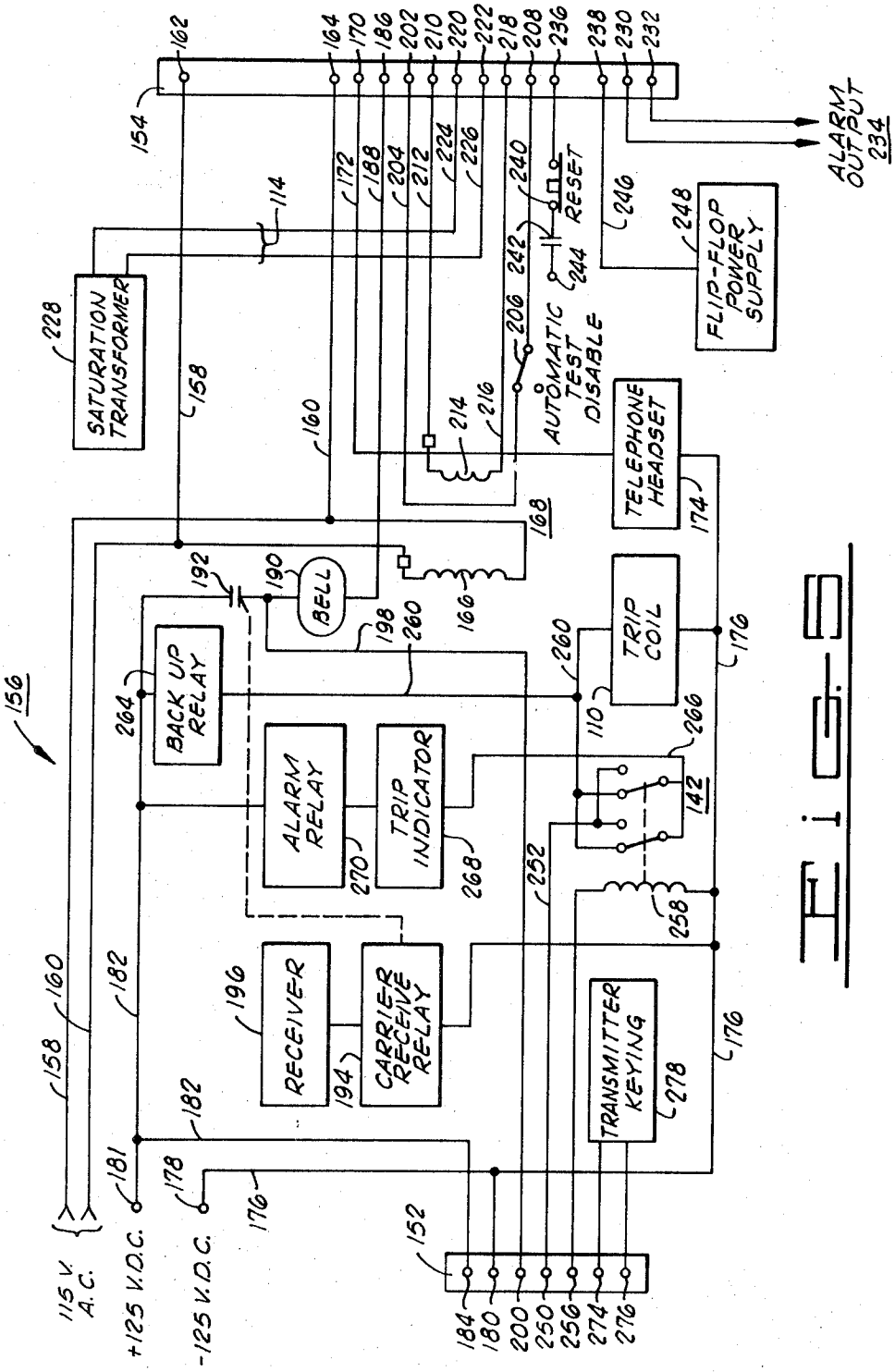


Fig. 5

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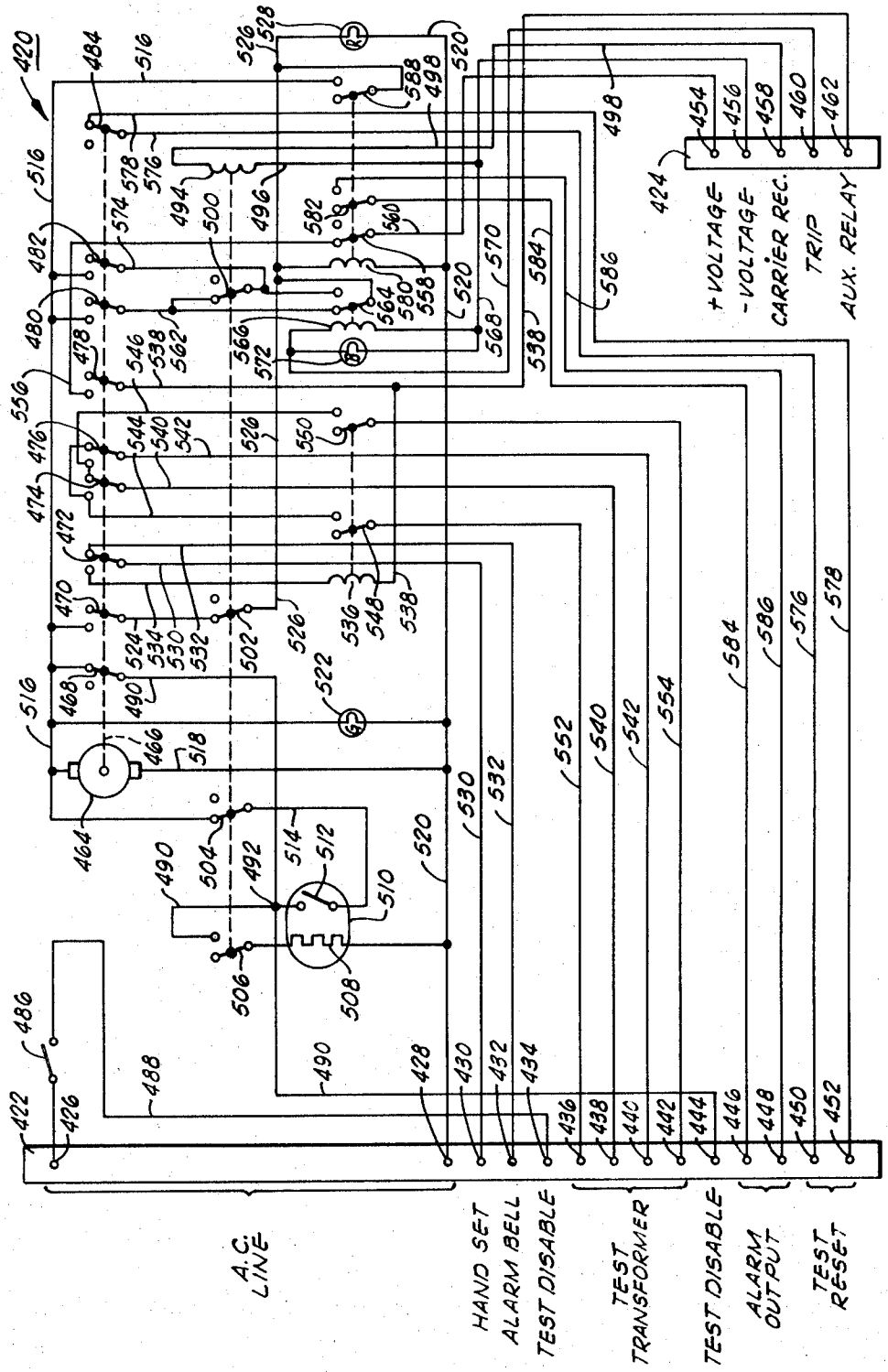


Fig. 7

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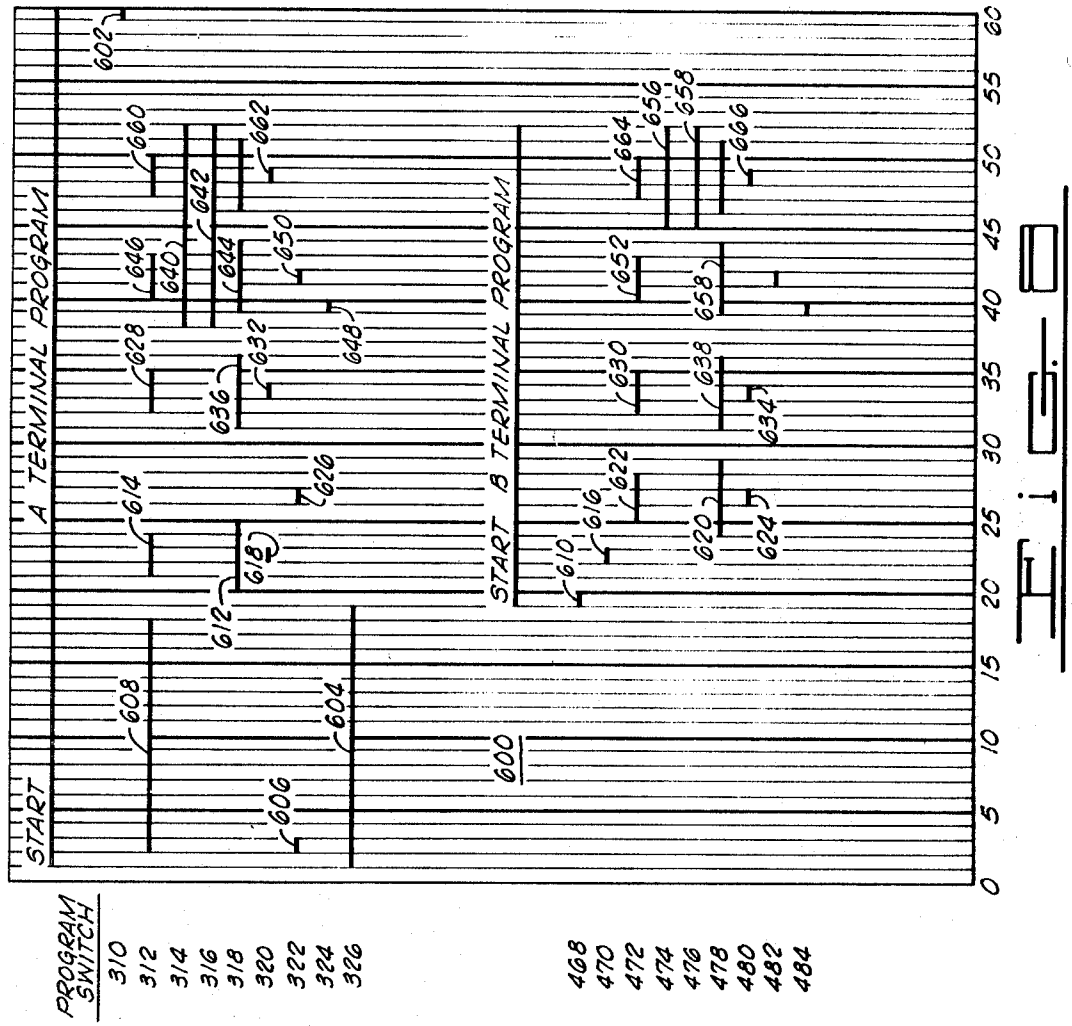


Fig. 5

PROGRAM SWITCH

310 312 314 316 318 320 322 324 326

468 470 472 474 476 478 480 482 484

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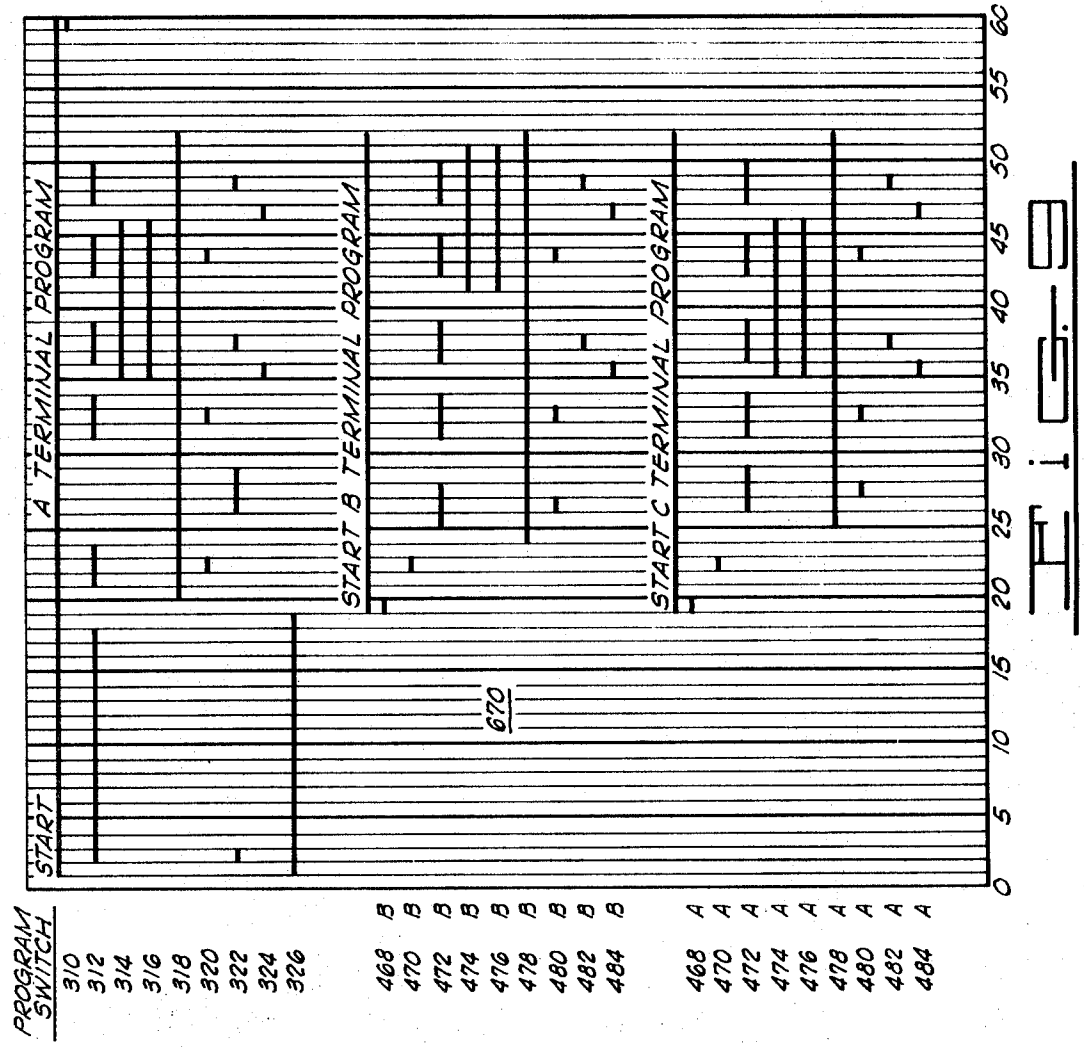


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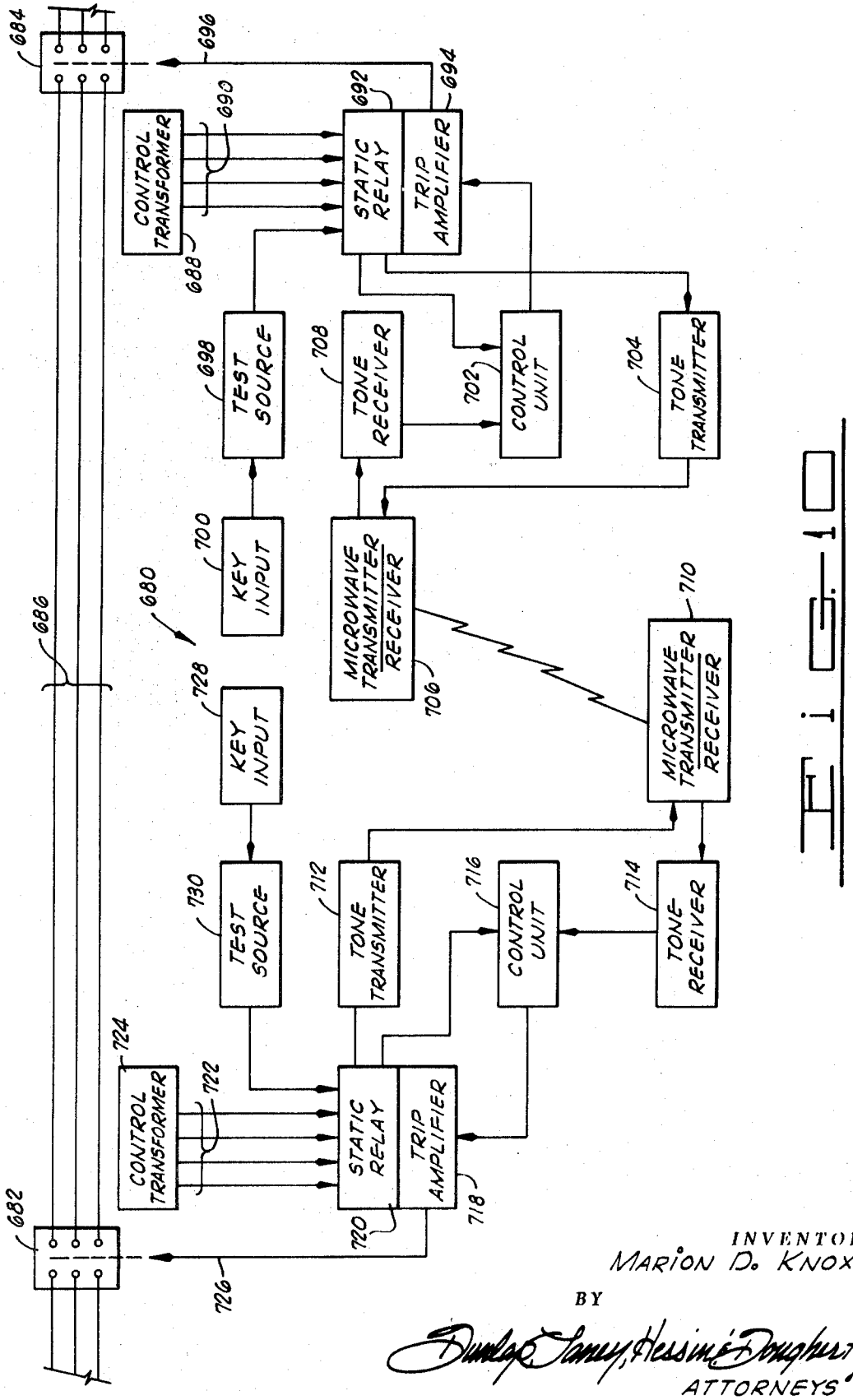


Fig. 10

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AUTOMATIC TEST APPARATUS FOR PHASE COMPARISON PROTECTIVE RELAY SYSTEMS AND THE LIKE

BACKGROUND OF THE INVENTION

1. Field of the Invention

The invention relates generally to high voltage transmission line protective relay equipment and, more particularly, but not by way of limitation, it relates to apparatus for automatic testing of solid-state protective relaying systems.

2. Description of the Prior Art

Prior methods of testing of protective systems for high voltage transmission networks have been carried out manually by performance of prescribed operator manipulations and subsequent observations of meter readings, lamp indications, etc. In the prior types of protective relay systems, which may include either carrier-current or microwave equipment, it has been the general practice to make carrier transmission tests at specified intervals, for example, once per day. To accomplish this, it required that an operator at each terminal station send and receive specific signals, and that they thereafter log the pertinent findings as read from the respective receiver equipment, i.e. the normal, the reserve-signal or reduced power values, and whatever other standardized values as were received in accordance with the test program.

SUMMARY OF THE INVENTION

The present invention contemplates an interlinking carrier and relay testing system which can be installed at each terminal of a high voltage transmission network to carry out periodic checks upon the protective relay system by means of a programmed sequence of carrier transmission and reception checks as between the two or three terminal installations. In a more limited aspect, the testing system is comprised of a plurality of switching systems, each of which is controlled by a periodically actuated program switch to control the several functions of the carrier and relay equipment at each terminal. Thus, at each terminal in the protective relay system, two or three terminals or transmission line substations being the normal situation, there is an automatic test unit consisting of a programming switch which controls a plurality of switching assemblies to effect carrier output, verification ring back, presence or absence of simulated internal and external faults and security code, lockout of units, testing stop notice, and alarm functions in accordance with the test procedure as programmed.

Therefore, it is an object of the present invention to provide apparatus for automatically testing the carrier, the static relays and the control units in a high voltage surveillance network.

It is also an object of the invention to provide a system which enables periodic automatic testing of all functions of an electrical current transmission line protective relay system as utilized with either a carrier or microwave interconnection.

It is still a further object of the present invention to provide a phase comparison protective relay testing system which is programmable as to the sequence and type of test functions between terminals.

Finally, it is an object of the present invention to provide an automatic static relay testing system for use with either carrier or microwave systems which is compact, lightweight, and virtually trouble-free as regards maintenance problems.

Other objects and advantages of the invention will be evident from the following detailed description when read in conjunction with the accompanying drawings which illustrate the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a block diagram of power terminal interconnection utilizing test apparatus in accordance with the present invention;

FIG. 2 is a block diagram illustrating various possible modes of application of the present invention to electrical power distribution networks;

FIG. 3 is a block diagram of one form of terminal installation utilizing the present invention;

FIG. 4 is a schematic diagram of master terminal testing circuitry;

FIG. 5 is a schematic diagram of one form of interconnection circuitry as utilized in one form of the invention;

FIG. 6 is a partially schematic illustration of a program switch as utilized in the present invention;

FIG. 7 is a schematic diagram of a remote testing terminal constructed in accordance with the invention;

FIG. 8 is a program diagram which may be utilized in a two terminal testing system;

FIG. 9 is a program diagram which may be utilized in a three terminal testing system; and

FIG. 10 is a block diagram illustrating the use of the present invention for testing an alternative form of relay interconnecting system.

DETAILED DESCRIPTION OF THE INVENTION

FIG. 1 illustrates a typical form of electrical power transmission line with transmission proceeding from a source **10** to a power terminal **12** and power terminal **14** to a consumer **16**. Control surveillance of the transmission system includes electronic transmission equipments **18** and **20** interconnected at the respective power terminals **12** and **14** and in communication via a linkage **22**, e.g. wireless, coaxial cable, microwave transmission, pilotwire, etc. As regards the power terminals **12** and **14**, powerline faults occurring between stations in the area **24** would be designated internal faults, while line failures occurring in either of areas **26** or **28** would be termed external faults. It should be understood too that the terminal configuration may be variously interconnected as shown in FIG. **2**, as will be described.

The transmission equipment **18** functions with power terminal **12** in response to a control unit **30** which is interactively operable with an automatic test apparatus **32** and a protective relay **34** to effect the required safety cautions through line switching by control of terminal circuit breakers (not shown). Similarly, the transmission equipment **20** at power terminal **14** is controlled by a control unit **36** functioning with an automatic test apparatus **38** and protective relay **40**. Fault indications are derived from line voltage or current sensing at respective power terminals **12** and **14** via lines **42** and **44** for application to control units **30** and **36**, respectively. One terminal may be designated as central and it will then include an alarm and central control **46** for regulating the automatic test system as is carried out by the automatic test apparatus **32** and **38**, to be further described.

The terminal interconnection plan of FIG. **2** illustrates that the type and number of interconnections is practically unlimited. Thus, a power generator **50** supplies electrical power via line **52** to terminal **54** which performs various functions in different interconnections as regards its automatic test capabilities. Thus, terminals **54**, **56** and **58** constitute a three terminal power network wherein terminal **54** is the master or A terminal while terminals **56** and **58** are slave, or respective B and C terminal automatic testing stations. A two terminal network is formed by terminals **54** and **60** with terminal **54** still being the master or A terminal while terminal **60** is a B terminal testing station. A similar two terminal automatic testing network is formed by terminal **58** as master A terminal and a terminal **62** as a remote or slaved B terminal.

Interconnection of still another power generator or source **64** gives rise to further integration of the power grid. Thus, a terminal **66** may be a master terminal for both of terminals **68** and **70**. Each of the terminals **68** and **70** is then a slaved remote terminal responding to automatic test control functions as initiated from the A terminal **66**. In similar manner, terminals. grid interconnection between terminals **66** and **54** might find terminal **54** slaving to automatic test function output from the A terminal **66**. Any number of terminals through various interconnections are possible with but minor alterations in test programs as will be further described in detail.

While the present invention can be utilized to test various forms of carrier and microwave equipment utilizing any of several types of protective relay line control, the invention is particularly described herein with respect to a phase comparison relay system **80** as employed at a breaker **82** along high voltage power transmission lines **84**, **86** and **88**. The phase-comparison relay system **80** is a standard protective equipment such as is commercially available from the Westinghouse Electric Corp. of Newark, N. J. The phase-comparison relay system **80** may consist of a control unit **90** and a relay unit **92** functioning with a carrier equipment **94**, i.e. a transmitter **96** and receiver **98** operating through a selected transmission line **100**.

The relay unit **92** consists of a sequence network **102** which is connected to sense currents in the respective power transmission lines **84**, **86** and **88** to derive a matrix output for application to a high-low fault detector **104**. Fault detector **104** then provides a high-set output **106** and a low-set output **108** for control purposes as will be further described. A trip coil **110** controls tripping of the power line circuit breaker **82**.

The control unit **90** receives control output from sequence network **102** via input **110**, a sixty cycle half-wave voltage, which is supplied through a low pass filter **112** to a terminal **114**. Voltage at terminal **114** is then applied on a line **116** to modulate the carrier transmitter **96** when applied in coincidence with a low-set output on lead **108** from fault detector **104**. Keying of the carrier transmitter **96** then provides carrier output via transmission line **100**.

The voltage from junction **114** is also applied through a local amplifier **118** which includes phase delay with input to a phase comparison circuit **120**. Sixty cycle half-wave pulses from a remote terminal are received via transmission line **100** to carrier receiver **98** whereupon its output is conducted through a remote amplifier **122** for application to phase comparison circuit **120**. The output of phase comparison **120** is effectively a comparison of the local voltage on line **124** and a remote voltage on line **126** to derive a trip voltage on line **128**. If the phase comparison **120** indicates in-phase voltages on leads **124** and **126**, an internal fault is existent, and output on lead **128** is applied through a time delay **130** to a flip-flop **132** which actuates a trip amplifier **134**. The high-set output from fault detector **104** on lead **106** is applied to enable the flip-flop **132**. Output from trip amplifier **134** is them applied on line **136** to the tripping relay **138**.

An automatic test apparatus **140**, the subject of the present invention as will be further described, is interactively connected with each of the carrier transmitter **96** and carrier receiver **98**, as well as sequence network **102** and the tripping relay **138**. The automatic test apparatus **140** functions with an auxiliary relay **142**, periodically, to check selected terminals of the relay carrier system including such as the associated control unit **90**, relay unit **92** and carrier set **94**. While the structure of FIG. **3** represents equipment at a single terminal of a power transmission line, it should be understood that similar apparatus will be located at each terminal, and that the automatic testing system will function between terminals in selected combinations of two or three.

Referring now to FIG. **4**, an automatic test unit **150**, a master of A terminal tester, is interconnectable by means of terminal boards **152** and **154** into an associated relay system. The interconnection diagram of FIG. **5** illustrates such interconnection connection from respective terminal boards **152** and **154** to the specific components of the control unit, relay unit, and carrier set. An interconnection circuit **156**, as shown in FIG. **5**, receives 115-volt AC line input via leads **158** and **160** for application in parallel to terminals **162** and **164** of terminal board **154**, as well as to a primary coil **166** of a test transformer **168**.

With further reference to terminal board **154**, a terminal **170** is connected to a lead **172** which is connected to telephone hand set unit **174** with return to a negative 125-volt DC lead **176**. The negative 125-volt DC lead **176** leads up to voltage input terminal **178** as well as to a terminal **180** on terminal board **152**. Positive voltage of 125 volts DC is applied at terminal **181** for distribution throughout interconnecting unit **156** via voltage lead **182**, the lead **182** also connected to a terminal **184** of terminal board **152**. A terminal **186** of terminal board **154** is connected through a conductor **188** to an alarm bell **190**, and the alarm bell **190** is energized by means of carrier receive relay contacts **192** which connect to the plus DC voltage lead **182**. The relay contacts **192** are energized closed upon energization of carrier receive relay **94** which is connected for actuation between carrier receiver **196** and the minus DC voltage lead **176**. The plus DC side of the alarm bell **190** is connected by means of a lead **198** to a terminal **200**, the carrier receive terminal, of terminal board **152**.

Returning again to terminal board **154**, a terminal **202** is connected to a lead **204** in series with a normally closed automatic test disable switch **206** which leads back to terminal **208**. A terminal **210** connects to a lead **212** in series with a secondary **214** test transformer **168** with return via lead **216** back to a terminal **218** of terminal board **154**. Terminals **220** **222** are each connected to respective leads **224** and **226** which are connected to the primary of a saturation transformer **228**. Saturation transformer **228** includes a phased array of control transformers in inductive relationship to the power transmission line and it serves to pick up and present any fault currents during fault conditions.

Terminals **230** and **232** provide connection to an alarm output **234** for effecting a suitable form of alarm actuation. Terminals **236** and **238** provide flip-flop reset energization as terminal **236** is connected through a reset switch **240** and a normally open fault detector contact **242** to a reset contact **244** which is located on the control unit flip-flop circuit (e.g. flip-flop **132** of FIG. **3**). The remaining terminal **138** is connected by means of a lead **246** to a flip-flop power supply **248**.

Referring again to secondary terminal board **152**, a terminal **250** is connected through a conductor **252** to a pair of normally open contacts of the auxiliary relay **142**. Terminal **256** is connected directly to one side of relay coil **258** of auxiliary relay **142** with return to the negative DC voltage lead **176**. The normally closed contacts of auxiliary relay **142** are connected in parallel to a lead **260** which leads to the trip coil **110** (FIG. **3**) which is returned through negative DC voltage lead **176**, and the lead **260** is also applied through a backup relay **264** to the positive DC voltage lead **182**. A lead **266** from the parallel-wiper contacts of auxiliary relay **142** is connected in series through a suitable trip indicator **268** and alarm relay contact **270** with return to the positive voltage lead **182**. The remaining terminals **274** and **276** of secondary terminal board **152** are connected to a transmitter keying circuit **278** which effects control of the carrier or such transmitter equipment which is associated with the particular terminal installation.

Returning again to FIG. **4**, the master or A terminal test unit **150** is energized by AC line input at terminals **162** and **164**, and energization is enabled by a start switch **289** which applies the AC line voltage across a synchronous timing motor **282**. The synchronous timing motor **282** may by any of various commercial types which include an associated gear box (not specifically shown) for reducing output rotation to a low rate of angular advancement. Thus, in one form of the invention, it is found desirable to employ a programmable timer motor **282** which effects closure of a timer switch **284** periodically. This timing or the frequency of closure of timer switch **284**, can be varied in accordance with the exigencies of particular equipment applications.

The start switch **280** applies the AC line voltage through a lead **288** to test board terminal **208** for circuit through the automatic test disable switch **206** (FIG. **5**) for return through terminal **202** and a lead **290** to an AC energizing lead **292**. When the timer switch **284** is closed, the AC energizing voltage from lead **292** is applied through an energizing coil **294** of time delay **296** with return to the other side of the AC line, a lead **298** to terminal **164**. AC voltage from junction point **300** is conducted through time delay switch contacts **302** for a period of about 10 seconds and through a lead **304** to one side

of a programming motor **306**. AC initiation to lead **304** is also conducted through a suitable form of counter **308** with return through the remaining AC lead **298** to provide a testing tally.

The programming motor **306** effects program control of a plurality of program switches **310, 312, 314, 316, 318, 320, 322, 324,** and **326**. The program switch **310**, the "test cycle" program switch, will be held in the open position (opposite that shown) when the test unit **150** is in its standby or quiescent state. Starting of rotation of program motor **306** upon closure of timer switch **284** will then allow closure of the "test cycle" program switch **310** to supply energizing AC voltage from lead **292** through a lead **328** and **330** to maintain energization of the program motor **306**. It may also be noted that a manual test switch **332** is provided to enable an operator to initiate a test cycle at other than times dictated by timer motor **282** and timer switch **284**. Depression of pushbutton switch **332** will apply AC voltage from lead **292** onto lead **304** to energize the program motor **306**.

FIG. **6** illustrates one form of program motor **306** as it may be associated with suitable programming structure. A motor-driven program switch **334** is similar to structure which is fully disclosed in U.S. Pat. No. 3,414,773, also assigned to the present assignee. The program switch **334** embodies a unique design which enables easy variation of the switch program. That is, a program drum **336** is divided into sixty equal, arcuate segments arrayed about its circumference, there being a groove **338** between each segment such that plastic placers or inserts **340** can be slid into the grooves **338** and aligned with particular ones of the leaf switch actuators (switches **310** through **326**) thereby to construct a desired relief or switch actuating structure. Thus, any program desired may be set into the program switch simply by adding or removing the plastic spacers **340** at the given program positions, i.e. a circumferential path in alignment with a particular one of the switches **310** through **326**. In the prototype equipment, the test units **150** employ motor **306** and gearing (not specifically shown) which generate one revolution per minute such that each segment of the program drum **118** is equal to 1 second in time.

Each of the program switches **310** through **326** performs a specific function through each 1 minute test cycle or revolution of the program drum as provided by program motor **306**. Thus, the "test cycle" program switch **310**, a normally closed switch is allowed to remain in its closed position, (as shown to provide holding energization to the program motor **306** through its entire 1 minute cycle. At the end of the cycle, a single program spacer **340** is engaged to open the switch **310** and stop the revolution of the program motor **306**. A program switch **312**, the "open alarm bell" switch, is normally closed to provide a connection between leads **342** and **344** to terminals **170** and **186** of terminal board **154**. When actuated, program switch **312** connects the lead **342** to lead **346** which provides energizing connection to a relay **348** when certain additional enabling conditions are met, as will be further described. Program switches **314** and **316** are designated "change polarity" switches as they serve to reverse the polarity of voltage at test transformer contacts **210, 220, 222** and **218**. The terminals **220** and **222** are connected via leads **350** and **352** to the respective wiper contacts of switches **314** and **316**. Switch connections are then alternated between leads **354** and **356** which, when relay **348** is actuated to close contacts **358** and **360**, are connected to respective leads **362** and **364** leading to terminals **210** and **218**.

The "open trip circuit" program switch **318** is in a normally open position with wiper lead **366** leading to the "auxiliary relay" terminal **256** of terminal board **152**; a parallel branch of lead **366** also provides connection to the relay coil **348**. Upon actuation, program switch **318** is closed for connection to a lead **368** through a relay contact **370** and lead **372** to the plus 125-volt DC source or terminal **184** of terminal board **152**. The nest program switch **320** serves a "verify local alarm and trip" function and it is normally open but actuated closed to connect the AC voltage lead **292** to a lead **374**.

A green lamp **380** is energized by lead **328** from program switch **310**, i.e. in parallel with program motor **306**, such that it indicates the test cycle "on" that time when program motor **306** is running. A blue indicator bulb **382** is connected for energization between one of the relay trip terminals **250** and the negative DC voltage terminal **180** of terminal board **152**, and this blue indicator **382** is energized in response to a trip condition switched through the auxiliary relay coil **258** (FIG. **5**), as connected via lead **383** to terminal **250**. A red indicator lamp **384**, the "alarm" indicator, is energized to indicate the alarm condition as will be further described below. The lamps **380** and **384** may be standard AC indicator bulbs while the blue lamp **383** is a DC lamp having a suitable resistance value.

A terminal trip relay **386** is connected in parallel with the blue indicator **382** and it is energized during the "trip" condition to control the relay contact **388** such that lead **374** from program switch **320** is removed from connection to a lead **390** which provides energization to the red "alarm" indicator lamp **384**. This removable of connection between lead **374** and lead **374** and lead **390** also disables the possibility of energization of an alarm relay **392** under control of the "verify local alarm and trip" program switch **320**. Alarm relay **392** controls a plurality of contacts **370, 394** and **396**. Contacts **394** are normally open as between the alarm output terminals **230** and **232** of terminal board **154**; and relay contacts **396** are normally open between the voltage source lead **390** and a lead **398** in series with a normally closed "reset" switch **400** i.e., conventional pushbutton type of switch which is returned to the AC lead **292**.

A carrier receive relay **402**, connected between the negative voltage terminal **180** and the carrier receiver terminal board **200** of terminal board **152**, is energized in response to closure of relay contacts **192** of carrier receive relay **194** (FIG. **5**). The carrier receive relay **402** controls relay contact **404**, a normally closed contact, to open up electrical contact between lead **374** from program switch **320** and a lead **406** connected to the normally open contact of relay contact **388** of the relay **386**. A parallel connection of lead **406** is also applied to the wiper contact of the "verify remote alarm" program switch **322**.

Alarm output at terminals **230** and **232** of terminal board **154** is provided from relay contacts **394** by respective leads **408** and **410**. The alarm output would be in the form of a switch closure at relay contact **394**. The test reset output at terminals **236** and **238** is provided from the "reset" program switch **324** via leads **412** and **414**, respectively. Closure of the "carrier start" program switch **326** provides switch actuation through terminals **274** and **276** of terminal board **152** to the transmitter keying circuit **278** (FIG. **5**).

FIG. **7** illustrates a B or C terminal, or a remote test unit which functions in coaction with the master test unit **150** to carry out the system test. The remote test unit **420** is generally similar to the master test unit **150**, but it is characterized by absence of some master control components. Thus, primary and secondary terminal boards **422** and **424** provide all interconnection contacts. The terminal board **422** provides 115-volt AC line voltage input at terminals **426** and **428**, and the terminals **430, 432** and **434** provide respective connections for "hand set," "alarm bell," and "test disable." The "test transformer" connections, four in all, are applied at contacts **436, 438, 440** and **442**, and a second "test disable" connection is made at contact **444**. Further, contacts **446** and **448** receive "alarm output" connection while a pair of contacts **450** and **452** provide the necessary "test reset" interconnection.

The secondary terminal board **424** receives positive and negative DC voltage supply at respective terminals **454** and **456**, with "carrier receive," "trip input" and "auxiliary relay," connections being made at the respective terminal contacts **458, 460** and **462**. In general then, the input connections for the remote test unit **420** are similar to those for the master test unit **150**, and a similar type of interconnection circuitry, such as is shown in FIG. **5**, is employed as the interface structure.

Also, a similar type of program switch is utilized in the remote test unit **420**, i.e. a program motor **464** providing output motion via dashline **466** to provide periodic actuation of the respective program switches **468, 470, 472, 474, 478, 480, 482** and **484**. The program assembly consisting of program motor **464** and the plurality of switches **468–484** is preferably a drum-type utilizing the plurality of switches as described in FIG. **6**, and as fully set forth in the prior issued U.S. Pat. No. 3,414,773 which is the property of the common assignee.

The AC energizing voltage is applied through a start switch **486** through a lead **488** and terminal **434** to an external circuit interrupter, e.g. "test disable" switch **206** of the FIG. **5** interconnection unit **156**. The energizing voltage is then returned via terminal **444** and a lead **490** to a junction **492** which provides energizing voltage distribution via parallel leads **490** to fulfill several start-up functions. First, since the remote test unit **420** is started upon receipt of carrier energy from the master unit, a carrier receive relay **494** is connected via leads **496** and **498** between terminals **456** and **458**, respectively, of terminal board **424**, and it is energized to provide actuation of respective relay contacts **500, 502, 504** and **506**. The relay contact **506** is then closed to connect AC energizing voltage from lead **490** through a relay coil **508** of time delay relay **510** to close relay contact **512** for a time delayed interval, e.g. 15 seconds, such that energizing voltage is available on lead **514**. However, relay contact **504** will also have been opened so that AC energization must proceed from voltage junction **492** of lead **390** through the "test cycle" program switch **468**, which will have been moved to its closed or normal position (as shown), to provide AC energization along lead **516**. The AC on lead **516** energizes program motor **464** to begin its constant, programming revolution to control the respective program switches **468** through **484**. The other side of program motor **464** is returned by a lead **518** and a lead **520** to the other side of the AC input at terminal **428**. A green indicator lamp **522** is connected between the energizing lead **516** and the AC lead **520** to provide lamp energization during the test cycle.

Program switch **470**, the "lockout" switch, is actuated to make connection between the AC energizing lead **516** and a lead **524** to the normally closed position of relay contact **502** of the carrier receive relay **494**. The wiper connection of relay contacts **502** is connected to a lead **526** and alarm indicator **528**, a red lamp, with return to AC lead **520**. The "test key" program switch **472** provides the functions of opening the alarm bell circuit and keying the test source. The wiper position is connected to a lead **530** leading to terminal **430**, the handset terminal of terminal board **422**. The normally closed contact is connected by a lead **532** to the alarm bell terminal **432** of the terminal board **422**, and the normally open contact connects by a lead **534** to relay **536** which is returned by means of a lead **538** to the relay trip terminal **462** of secondary terminal board **424**.

The program switches **474** and **476** combine to carry out the "change of polarity" function with respect to the test voltage. Thus, a test voltage present at terminals **436** and **442** via leads **552** and **554** is supplied through relay **536**, i.e. contacts **548** and **550**, to the respective program switches **474** and **476**. The wiper input positions of contacts **548** and **550** are then connected to leads **552** and **554** which are connected to the respective test transformer terminals **436** and **442**.

The program switch **478** functions to open the trip circuit and it is normally open with one contact connected to a lead **556** and the wiper contact connected to the lead **538** which is connected to auxiliary relay terminal **462**. Lead **556** is connected through a relay contact **558** which is normally closed to receive positive DC voltage via lead **560** from terminal **454**. The "verify local alarm and trip" switch **480** is normally open but actuated closed to connect AC voltage from energization lead **516** through a lead **562** which is connected in parallel to normally closed relay contact **500** as well as to a contact **564** of a relay **566**. Relay **566** is connected via leads **568** and **570** between terminals **456** and trip input terminal **560**. A blue indicator lamp **572**, a DC lamp, is connected in parallel with the coil of relay **566** to indicate the "trip" condition when relay **566** is energized.

The program switch **482** functions to "verify remote alarm with no trip" condition, and it is normally open but actuatable to connect the AC energizing lead **516** to a lead **574**. Lead **574** connects to the common or wiper position of relay contact **500** as well as to the normally open position of relay contact **564** of the relay **566**. Finally, the program switch **484** carries out the "reset" function as it is normally closed to provide short circuiting between leads **576** and **578** which are connected the "test reset" terminals **450** and **452** of terminal board **422**.

An "alarm" relay **580** is connected between lead **526** and the AC lead **520** and it is energized to provide several control functions. The contact **558**, which is normally closed to conduct positive DC voltage from terminal **454** and lead **560**, is opened to prevent energization of relay **536** or DC output to the auxiliary relay **142** (FIG. **5**) via **462**. A normally open relay contact **582** may be energized to complete the alarm circuit between leads **584** and **586** to the alarm output terminals **446** and **448** of terminal board **422**. The remaining relay contact **588** is normally open and energized closed to connect the AC energizing lead **516** to the intermediate energizing lead **526** which includes holding energization of the "alarm" indicator lamp **528** and relay **580**.

OPERATION

The operation description is set forth with respect to a two terminal testing system, i.e. a master A terminal and a remote B terminal. FIG. **8** illustrates a two terminal program diagram for both the A and B terminals. Thus, FIG. **8** represents the circumferential field of program drum **336** (FIG. **6**) which has 60 segments per complete revolution, and the plurality of horizontal black lines indicate the position of plastic spacers **340** (FIG. **6**) disposed thereon for actuation of each of the respective A terminal program switches **310** through **326** and B terminal program switches **468** through **484**.

It is generally the procedure to begin testing operation with the transmitters adjusted to generate some designated percentage of normal or full output, i.e. a reduced power output. This then enables what is effectively a reduced power test between the particular terminals, with full power tests and verifications effected thereafter.

Program test is initiated at the A terminal (FIG. **4**) as timer motor **282** closes switch **284** to apply AC energization through time delay relay **296** to initiate rotation of program motor **306**. In the "off" position, program motor **306** will be held deenergized by a program spacer **602** (FIG. **8**) which terminates and holds off energization of the test apparatus after each test cycle. Initial energization of program motor **306** through time delay relay contact **302** is sufficient to move the program drum so that program spacer **602** no longer holds program switch **310** open, and in its closed position it maintains energization for the following 59 segments of program drum rotation. The program spacer **604** is arranged to actuate program switch **326**, the carrier test circuit, from positions two through 19 such that program switch **326** keys the carrier on for 18 seconds. At position three, program switch **322** responds to a program spacer **606** to verify reception of a local alarm, absence of verification serving to stop the test in progress. The program switch **312** is actuated by program spacer **608** to hold open the local alarm bell circuit until position 19.

Meanwhile, at terminal B, carrier received indications will cause actuation of a relay **494** to close relay contact **506** such that the time delay relay **510** is energized with current conduction through the coil **508**. When the relay **494** ceases conduction, after receiving at least 15 seconds of "carrier on" indication, the remote program motor **464** is energized thru contact **504** and remote program switch **468** is moved out of contact with program spacer **610** such that program motor **464** (terminal B) remains energized for the next 59 seconds of the du-

ration of its respective test cycle. At this occurrence, the respective master and remote test units **150** and **420** are running and they are in synchronization.

It may be noted that telephone conversations, telemetering transmissions or other supervisory control transmissions in addition to fault conditions might cause energization of a long pulse of carrier which could start the remote terminals. However, time delay relay **296** protects such that carrier transmission of less than 15 seconds is not able to start the running and synchronization of program motors at remote terminals. After starting, the remote terminal must still verify a security code before proceeding with the remainder of the test cycle.

Thus, at position **20**, a master terminal program spacer **612** actuates program switch **318** to energize the related auxiliary relay **142** (FIG. **5**). Actuation of the auxiliary relay **142** opens the energizing circuit via lead **260** to the actual equipment trip coil **110** to remove effects of actuation of the alarm relay **270**. Thus, conduction during simulated fault condition is from lead **266** through auxiliary relay **142** to lead **252** and terminal **250** (FIG. **5**) to energize the terminal "trip" relay **386** of FIG. **4**. This also energizes the blue lamp **382** to indicate the trip condition.

Simultaneously, positive DC voltage is supplied from program switch **318** to the test enable relay **348**. Then, when program switch **312** is keyed by program spacer **614** from positions **22** through **24** of FIG. **8**, it serves to open the alarm bell circuit while energizing relay **348** to actuate contacts **358** and **360** closed so that they connect the test source potential to the static relay, i.e. the protective relay undergoing test at the particular terminal installation. In the present application, test source potential will be available on leads **350** and **352** to the terminals **220** and **222** (FIG. **4**) for conduction via leads **224** and **226** (FIG. **5**) to the primary of saturation transformer **228**.

In the case of a phase comparison protective relay system, as is primarily disclosed in respective FIGS. **4** through **8**, the low-set fault detector should operate to effect transmission of half cycle pulses from the respective carrier transmitter **96** FIG. **3**), while the high-set fault detector serves to generate the local trip condition in conventional manner. The trip condition will be indicated by illumination of the blue "trip" lamp **382** with relay **386** energized. At the B terminal, half cycle pulses must be received at the respective carrier receiver **196** with indication to the test unit **420** when program switch **470** closes for 1 second in response to program spacer **616** at position **23**, contact **502** must be actuated open or the system will alarm. The proper receipt serves to verify or effect a second portion of the security code, which, in turn, serves to keep the terminals unlocked and ready for testing.

Absence of the signal, i.e. when no half cycle pulses are received at the B terminal carrier receiver, the test unit **420** will alarm and lock out since failure to apply a carrier receive input at terminal **458** of terminal board **424** fails to energize carrier receive relay **494** to open the contact **502**; and, any closure of program switch **470** will then effect the alarm condition by illuminating red lamp **528** and actuating alarm relay **580**. Also in position **23**, a terminal A program spacer **618** effects closure of program switch **320** to verify the trip relay **386**, i.e. AC energizing voltage as applied from **292** through lead **374** and relay contact **388** to actuate the red alarm lamp **384** and the alarm relay **392**. If test security is true, closure of program switch **320** serves to verify that trip relay **386** is energized and that carrier relay **402** is energized.

At the B terminal, position **25**, program spacer **620** actuates program switch **478** to effect closure of that auxiliary relay **142** (FIG. **5**) which is associated with the B terminal. Energization of the auxiliary relay **142** (B terminal installation) opens the energizing circuit for the respective trip coil **110** to apply trip energizing power via lead **252** to the terminal **250** (FIG. **5**). This, in turn, provides connection across terminal **460** of input terminal board **424** of B terminal test unit **420** such that a trip energizes the blue "trip" lamp **572** and the trip relay **566**. Simultaneously, as the trip is opened, the positive DC voltage is supplied to relay **536** such that, upon keying of remote program switch **472** at positions **26–28** by program spacer **622**, the alarm bell circuit is opened and relay **536** is energized to connect the test source potential to the primary of the respective saturation transformer.

The remote terminal static relay then must also operate to transmit half cycle pulses of carrier and trip. Tripping will be indicated by the illumination of the blue "trip" lamp **572**. At position **27**, program switch **480** is actuated in response to program spacer **624** and this serves to verify the trip relay **566** as carrier receive relay **494** is energized. At the master A terminal, program switch **322** is closed in response to program spacer **626** at position **27** and this verifies reception of carrier from the remote terminal, but without local tripping as respects the master terminal equipment.

Program spacers **636** and **638** (remote) control respective program switches **318** and **478** which operate to open the respective trip circuits by energizing the related auxiliary relays **142** at each of the master and remote terminals.

An internal fault is simulated when master program switch **312** is keyed by program spacer **628** at positions **33** to **35**, and remote program switch **472** is keyed by program spacer **630** at the same position, respective local trips being keyed thereby. The auxiliary relay **142** at each terminal passes the trip to relays **386** and **566** for verification at position **34**, i.e. a plastic spacer **632** effecting program switch **320** and, at the remote terminal, a plastic spacer **634** affecting program switch **480**. Actuation of the respective program switches **320** and **480** serves to apply the AC energizing voltage to the contacts of the respective trip relays **386** and **566** thereby to verify their switch setting.

The master and remote terminals can change the phase of their respective test source potentials by keying of program switches **314** and **316** at the master terminal, and program switches **474** and **476** at the remote terminal. Thus, program spacers **640** and **642** actuate program switches **314** and **316** such that the A terminal test voltage phase is reversed at test transformer terminals **220** and **222**. Output is not realized until DC is supplied to relay **348** in response to closure of program switch **318** under control of program spacer **644**. Presence of program spacer **646** to actuate program switch **312** completes the low side energization of relay **348** which applies the test transformer output in the proper reversed phase. Program spacer **648** then closes programs switch **324** to effect test reset and, 2 seconds later, program spacer **650** effects closure of program switch **322** to verify the test condition.

Proper coordination with the A terminal carrier transmission is then made at the B terminal through switch closure by the program spacers **652** and **658**. Comparisons of local and received signals are made at the terminals to verify the reception of alarms, but without the tripping conditions. These indications again must be verified or each terminal will alarm and lockout, and the test will be stopped with alarms being reported to and stored at the master terminal test unit **150**.

The B terminal program at position **45** then reverses the phase of its test source potential by keying program switches **474** and **476** by means of the program spacers **656** and **658**. At this time all test potentials are again in phase. The simultaneous comparisons of local tripping conditions are made when the master remote switch **312** is keyed by the master A terminal program spacer **660**, verification coming with closure of program switch **320** in response to program spacer **662**. At the same time the remote program switch **472** is keyed in response to program spacer **664** with a verification by actuation of the program switch **480** in response to spacer **666**. If at any time the units fail to obtain the proper starting signal, ring back, presence or absence of simulated faults along with the proper security codes; all units will alarm, lockout, stop testing and the proper alarm indications will be reported to the master terminal. The alarm indications, which may be repeated at some designated control center, must be personally ackowledged by an attendant and manually reset at the master terminal.

It should be fully understood that a test system constructed in accordance with the present invention is applied to selected test terminals or stations. Thus, a two or three terminals automatic testing system can be installed for coactive operation at two or three terminals. The program **670** of FIG. **9** illustrates a three terminal program with proper program spacer arrays for each of terminals A, B and C. Terminal A is the master terminal maintaining the control central and alarm functions while both of terminals B and C are made to slave to the master terminal A.

FIG. **10** illustrates another form of commercially available transmission line surveillance network which can be tested with the automatic testing system of the invention. It should be understood too that various surveillance networks using different subcombinations of commercially available type are compatible with the present invention. In FIG. **10**, the surveillance network **680** is a microwave transmission link shown installed between two terminals, including circuit breakers **682** and **684**, along a powerline **686**.

At circuit breaker **684**, a control transformer **688** is located in sampling proximity to the powerline **686** to provide a sequence network output via connection **690** to a static relay **692**. The static relay **692** would include a trip amplifier **694** and a connection **696** for breaking the circuit. The static relay **692** may take any of the various forms; however, the present application is directed mainly to the phase comparison type of relay. Thus, a suitable test source **698** may be energized by a key input **700** to provide a suitable test signal input to static relay **692**, which static relay **692** is in coacting interconnection with a control unit **702** of conventional type. A low-set output from static relay **692** is utilized to key a tone transmitter **704** which, in turn, modulates a microwave transmitter/receiver **706**, and also to supply an input control signal to control unit **702**.

The microwave transmitter/receiver is a conventional UHF or SHF transmitter as utilized for telemetric purposes. Suitable microwave telemetric transmitter/receiver equipment is, for example, commercially available from the Leukurt Electric Co. of San Carlos, Calif. Energy received by the microwave transmitter-receiver **706** is applied to a tone receiver **708** which demodulates and applies its output to the control unit **702** to complete the control function. Suitable forms of tone receivers and transmitters, as may be employed for tone receiver **708** and tone transmitter **704**, are Model MC22 which are commercially available from the Motorola Company of Chicago, Ill.

The other terminal **682** includes similar equipment. That is, a microwave transmitter/receiver **710** functions in coaction with a tone transmitter **712** and a tone receiver **714**, each being interconnected to a control unit **716**. An output from control unit **716** is applied to a trip amplifier **718** which is an integral component of a static relay **720**. The static relay **720** is connected by means of the connection **722** to a control transformer **724** while maintaining a mechanical disabling connection **726** with the circuit breaker **682**. The key input **728** and test source **730**, similar to that at the other terminal or proximate the circuit breaker **684**, are included with input interconnection to static relay **720**.

Interconnection of the test equipment to carry out the various test, verify, alarm, etc. functions is easily carried out, interconnection being similar to that previously described in FIG. **5**. Inputs and outputs relating to the prior carrier functions would be applied to the like components of the microwave transmitter/receiver system, and the control interconnection relating to the static relay, control unit and trip amplifiers would remain the same.

The foregoing discloses a novel automatic testing system for use in maintaining high voltage electrical transmission networks. The test system is capable of interconnection for coactive testing operation automatically and between any two or three terminal stations in a power distribution grid. In addition, the automatic test can be utilized with various forms of communication equipment, i.e. carrier equipment, microwave equipment, telephone hookup, etc. Testing may be effected in coaction with various types of the conventional protective relays such as directional, phase comparison, impedance directional comparison, conductance directional comparison, and combination whether solid-state or hard tube types.

While it is intended that circuit components utilized in the present invention may be of the time-proven types capable of heavy duty, long time operation with little or no maintenance, it is also contemplated that the entire system can be constructed from the more recently developed solid-state components. Such choices as to components and overall types of construction may be dictated by the exigencies of each particular application.

Changes may be made in the combination and arrangement of elements as heretofore set forth in the specification and shown in the drawings; it being understood that changes may be made in the embodiments disclosed without departing from the spirit and scope of the invention.

What is claimed is:

1. Apparatus for testing a plural terminal powerline protective relay system which includes a transmitter and receiver interconnected with a control unit and protective relay connected to control a line circuit breaker assembly at each terminal, each of the transmitter and receivers being in mutual communication, the apparatus comprising:

first programming switch means located at a first terminal and being actuatable to function for a predetermined duration;

first control means which is actuated by said first programming switch means to energize the first terminal transmitter to transmit carrier energy;

second programming switch means located at a second terminal and being actuatable to function for a predetermined duration;

second control means which is actuated by the second terminal receiver upon receiving the transmitted carrier energy from said first terminal to actuate said second programming switch means to function for said predetermined duration;

first and second auxiliary relay means located at respective first and second terminals and being energizable to remove said circuit breaker assembly from control connection to said control unit and protective relay; and

first and second switching means controlled by respective first and second programming switch means to energize respective first and second auxiliary relay means during predetermined intervals of said predetermined duration.

2. Apparatus for testing a plural terminal powerline protective relays system as set forth in claim **1** which is further characterized to include:

third programming switch means located at a third terminal and being actuatable to function for a predetermined duration;

third control means which is actuated by the third terminal receiver upon receiving transmitted carrier energy from said first terminal to actuate said third programming means to function for said predetermined duration;

third auxiliary relay means located at said third terminal and being energizable to remove the circuit breaker assembly from control connection to said third terminal control unit and protective relay; and

third switching means controlled by the third programming switch means to energize a respective third auxiliary relay means during predetermined intervals of said predetermined duration.

3. Relay system testing apparatus for use with electrical transmission lines having plural terminals each of which includes an interconnected transmitter and receiver, ad a phase comparison protective relay and control unit, which control unit includes means for keying a respective transmitter with alternating, discontinuous fault voltages in response to a fault condition at the respective terminal, the test apparatus comprising:

first means at a first local terminal for generating a first fault voltage which simulates a first trip condition;

second means at a second remote terminal for generating a second fault voltage which simulates a second trip condition;

verification means receiving each of said first and second fault voltages to determine phase relationship thereby to indicate a predetermined fault condition relative to said first and second terminals; and

first and second program switch means automatically energized in synchronous relationship to actuate the respective first and second means simultaneously.

4. Testing apparatus as set forth in claim 3 which is further characterized to include:

first switch means actuated by said first program switch means to reverse the phase of said first fault voltage such that said verification means indicates a second predetermined fault condition.

5. Testing apparatus as set forth in claim 4 which is further characterized to include:

second switch means actuated by said second program switch means to reverse the phase of said second fault voltage such that said verification means indicates a different fault condition.

6. Test apparatus for use in testing a protective relay system functioning with an electrical transmission line wherein each of local and remote terminals interconnecting sald transmission line include a circuit breaker with trip circuitry to operate said circuit breaker upon reset fault indication, a transmission and receiver equipment, and a protective relay including control circuitry for keying said transmitter in response to locally detected fault indication signals and for comparing the phase of fault indication signal received from remote transmitters with the phase of fault indication signals generated at the local transmitter to determine if the fault is internal or external of the interconnecting transmission line, the test apparatus comprising:

program control means located at said local terminal and actuatable to effect selected operation of a plurality of program switches at differing intervals through a predetermined time sequence, each of said switches being connected to provide a program control output actuation;

starting means for actuating said program control means;

an electrical power supply;

auxiliary relay means connected to said circuit breaker trip circuitry to apply electrical power to said trip circuitry when said auxiliary relay means is deenergized such that the trip circuitry will operate said circuit breaker upon preset fault indication;

circuit means connecting a first program control output actuation of one of said plurality of program switches to energize said auxiliary relay means thereby to remove said electrical voltage to said trip circuitry to disable operation of said circuit breaker for the duration of said fist program control output actuation; and

fault simulation means energized by a second program control output actuation during said first program control output actuation thereby to energize said protective relay and control circuitry to key said transmitter and provide trip indication.

7. Test apparatus as set forth in claim 6 wherein said fault simulation means comprises:

transformer means connected to simulate a fault current indication as an AC electrical voltage; and

first relay means energized by a third program control output actuation of one of said plurality of program switches to apply said AC electrical voltage fault indication to said protective relay and control circuitry.

8. Test apparatus as set forth in claim 7 which is further characterized in that:

fourth and fifth program control output actuations of said plurality of program switches are periodically actuated to reverse the phase of the output AC fault indication voltage from said first relay means.

9. Test apparatus as set forth in claim 6 wherein said remote terminal also includes test apparatus comprising:

remote program control means located at said remote terminal and being actuatable to effect selected operation of a plurality of program switches at differing intervals through a predetermined time sequence, each of said switches being connected to provide a program control output actuation;

carrier relay means responsive to transmission from said transmitter at the local terminal to start actuation of said remote program control means;

a remote electrical power supply;

remote auxiliary relay means connected to said remote circuit breaker trip circuitry to apply electrical power to said remote trip circuitry when said remote auxiliary relay means is deenergized such that the remote trip circuitry will operate said remote circuit breaker upon preset fault indication;

remote circuit means at the remote station connecting a first program control output actuation of one of said plurality of program switches of the remote program control means to energize said remote auxiliary relay means thereby to remove said electrical voltage to said remote trip circuitry and to disable operation of said remote circuit breaker for the duration of said first program control output actuation; and

remote fault simulation means energized by a second program control output actuation during said first program control output actuation thereby to energize said remote protective relay and control circuitry to key said remote transmitter and provide a remote trip indication.

10. Test apparatus as set forth in claim 9 wherein said remote fault simulation means comprises:

transformer means connected to simulate a fault current indication as an AC electrical voltage; and

first relay means energized by a third program control output actuation of one of said plurality of program switches to apply said AC electrical voltage fault indication to said protective relay and control circuitry.

11. Test apparatus as set forth in claim 10 which is further characterized to include:

fourth and fifth program control output actuations of said plurality of program switches are periodically each actuated to reverse the phase of the output AC fault indication voltage from said first relay means.

12. Test apparatus as set forth in claim 6 wherein said starting means comprises:

synchronous motor means mechanically coupled with an electrical switch means, said motor means functioning to close said switch means at periodic intervals.

13. Test apparatus as set forth in claim 9 which is further characterized in that:

said starting means at the local terminal consists of an electrical switch closed at periodic intervals by a synchronous timing motor, and said remote terminal starting means is a relay means energized in response to receipt of carrier from the local transmitter to start a cycle of test operation at the remote terminal.