June 7, 1955 D. L. WYLIE ET AL 2,710,368

ELECTRONIC DIFFERENTIAL RELAY SYSTEMS

Original Filed May 25, 1950

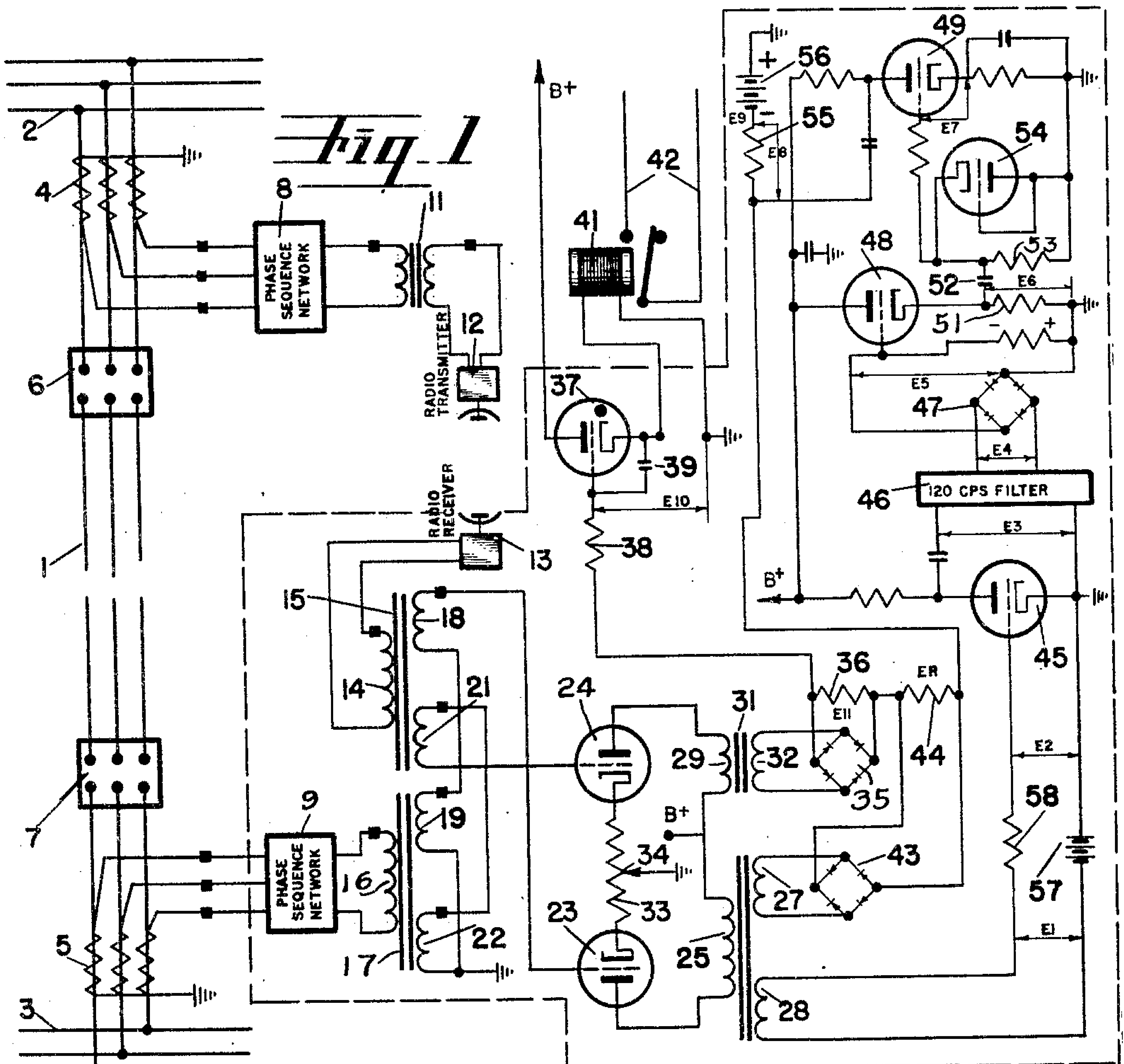

Fig. 1

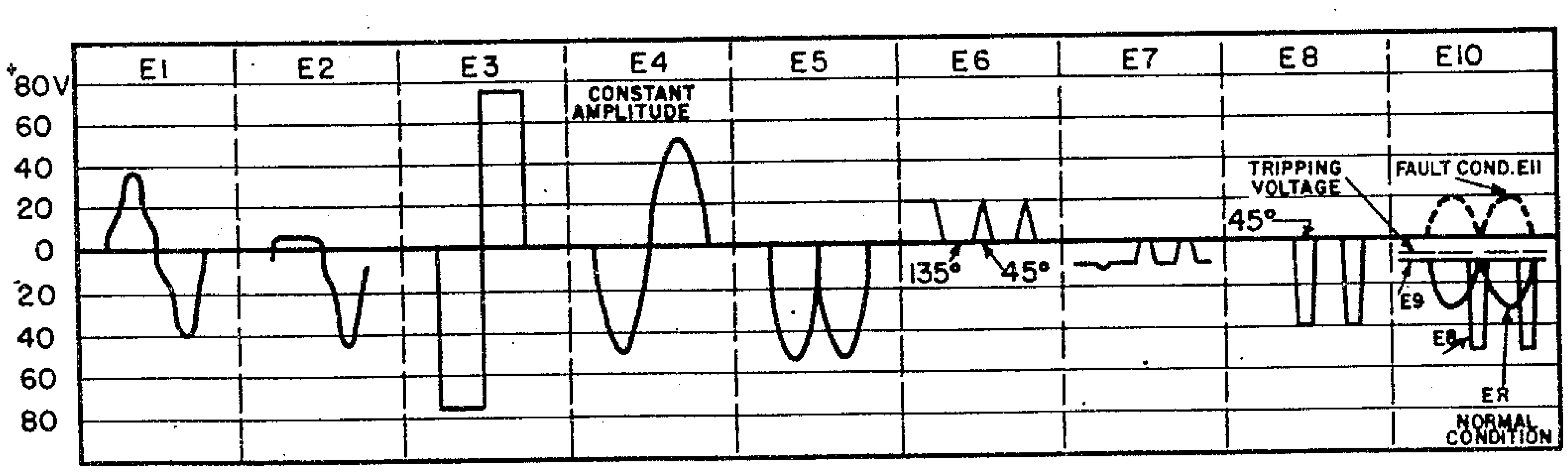

Fig. 2

INVENTORS
DONALD L. WYLIE
DONALD J. MARIHART

BY [signature]

ATTORNEY

2,710,368

ELECTRONIC DIFFERENTIAL RELAY SYSTEMS

Donald L. Wylie, Portland, Oreg., and Donald J. Marihart, Carnation, Wash., assignors to the United States of America as represented by the Secretary of the Interior

Continuation of application Serial No. 164,122, May 25, 1950. This application July 25, 1950, Serial No. 175,847

7 Claims. (Cl. 317—28)

(Granted under Title 35, U. S. Code (1952), sec. 266)

The invention described herein may be manufactured and used by or for the Government of the United States for governmental purposes without the payment of any royalty thereon in accordance with the provisions of the act of March 3, 1883, (22 Stat. 625), as amended by the act of April 30, 1928 (45 Stat. 467, 35 U. S. C., 1946 Ed. Sec. 45).

This application is a continuation of the pending Wylie and Marihart application Serial No. 164,122, filed May 25, 1950, now abandoned.

This invention relates to the protection of high voltage power transmission lines. It is concerned particularly with protective relay arrangements of the kind in which conditions at the two ends of a line are compared to determine the existence of a fault in the line. This invention can be regarded as a variety of pilot wire relay systems with the unusual feature of using a radio transmission system instead of a conventional pilot wire.

The principal object of this invention is to provide a fast and accurate protective relay system comparing current conditions at the ends of a line, and communicating between the ends of the line through a pilot connection channel. Another object is the production of a relay system which is faster than conventional electro-mechanical relay systems. Other objects are: to provide a system in which relay operation is definitely restrained and operated correctly in reference to line conditions; to provide in a relay system an arrangement of phased alternating and direct current circuits in which two sets of rectified waves overlap to avoid the momentary periodic decrease to zero of rectified pulses characteristic of the ordinary rectified output of a single-phase rectifier; to provide in a relay system, an arrangement whereby a plurality of restraints are present under normal conditions to avoid incorrect operation, in which actuating forces overbalance the restraints only under fault conditions; and to provide a system in which the magnitudes and phases of alternating currents in the system control direct currents which can be directly combined and used simply for operation of protective circuits which are inherently fast in their response to changing conditions.

What constitutes my present invention is set forth, with reference to the accompanying drawing, in the following specification and succinctly defined in the appended claims.

In the drawing, Figure 1 is a circuit diagram of a preferred form of embodiment of my invention, and Figure 2 is a graphical representation of certain potential differences existing in the circuits of my invention under specified conditions.

In Figure 1, a conventional polyphase electric power transmission line **1** terminating at substation busses **2** and **3** is equipped with conventional sets of current transformers **4** and **5** at busses **2** and **3**, respectively. The usual circuit breakers, **6** and **7**, are provided. Current transformer sets **4** and **5** are connected respectively to phase sequence networks **8** and **9** in ways known in the prior art. This

invention compares the two single-phase output currents of networks **8** and **9** in novel ways to be described.

The output of network **8** is delivered through a transformer **11** to a radio transmitter **12** which sends a signal to a radio receiver **13**. Receiver **13** delivers to input coil **14** of a transformer **15** a signal which is essentially in phase with the output of network **8**. The two signals will generally not be in exact phase coincidence due to the finite time required to propagate the power and microwave radio energies between the two line terminals. The communicating channel, in this instance consisting of radio transmitter and receiver, could under suitable conditions consist of solid conductor, transmission line carrier current, or any other applicable inter-connection. The output of network **9** is delivered in a way analogous to that of network **8** to a coil **16** of a transformer **17**. Transformers **15** and **17** are interconnected by output coils **18** and **19** and by coils **21** and **22**. The resultant voltage of coils **18** and **19** is impressed on the grid of a thermionic triode **23**. Similarly the resultant voltage of coils **21** and **22** is impressed on the grid of a triode **24**.

Under normal conditions of line operation, the currents in a particular conductor of line **1** are in phase. The corresponding voltages in transformer coils **18** and **19** are phased so as to be additive. The voltages in coils **21** and **22** are phased to be subtractive. If a fault occurs outside line **1**, the current therein will usually increase. This will cause the resultant voltage of coils **18** and **19** to increase. The resultant voltage of coils **21** and **22** is normally a small value. When a fault occurs outside the line **1**, any increase in current in the line, being the same at both ends, still leaves the resultant voltage at a small value. Actually the resultant voltage of coils **21** and **22** is arranged to be practically zero under normal conditions, and it remains practically zero for faults outside the protected line **1**.

When a fault occurs in line **1**, some current flows to the fault from both ends, thus producing components of current 180 degrees out of phase between the two ends. These out-of-phase components, when they appear in coils **18** and **19**, add to the voltage of one coil and subtract from the other. The resultant voltage of the two coils is thereby decreased in comparison with that voltage which would exist without the presence of out-of-phase components. The out-of-phase components, when they appear in coils **21** and **22** increase the resultant voltage from the normal resultant of practical zero. These conditions presuppose proportionality between the output of phase sequence network **8** and the output of radio receiver **13**.

The combination of networks **8** and **9**, and coils **21** and **22**, in the normal condition of practically zero resultant voltage together with the departure under fault conditions of the resultant voltage provides a reliable method of fault detection by comparing conditions at the two ends of line **1**. The additional combination of coils **18** and **19** in which the resultant voltage decreases under fault conditions contributes to additional reliability through differential effect between the two triodes **23** and **24**.

There are some fault conditions in which extreme unbalance of current magnitudes at the two ends of the line will cause an increase in the resultant voltage of coils **18** and **19** instead of a decrease as can be expected under ordinary fault conditions. It is necessary therefore to provide an adjustment of ratio between the outputs of triodes **23** and **24** to establish an optimum relationship between their relative effects. A potentiometer **33** connected between the cathodes of triodes **23** and **24** is grounded at the tap **34**. Adjustment of the tap **34** changes the ratio of the cathode to ground resistance for the two triodes. Shifting the tap **34** toward triode **23** decreases the grid bias voltage on triode **23** relative to that of triode **24**. The output of triode **24** is delivered to a transformer **31** which delivers to a full wave rectifier **35** the alternating component of the plate output of triode **24**. The output of rectifier **35** is impressed on a resistor **36** and the grid of a gas-filled triode **37**, such as a thyratron. A series resistor **38** and a by-pass condenser **39** are conventional parts of the thyratron circuit. Triode **37** operates a relay **41**, referred to as a "trip" relay. The contact terminals **42** of relay **41** control the actual operation of circuit breaker **7**. The inter-connection between terminals **42** and the mechanism of circuit breaker **7** being conventional are omitted from the drawing.

The alternating current component of the output of triode **23** is delivered by transformer **25** through coil **27** to a rectifier **43**. The output of rectifier **43** is impressed on a resistor to develop a voltage which is algebraically added to the voltage developed by resistor **36**. The resultant voltage across resistors **36** and **44** is impressed on the grid of gas triode **37** through resistor **38**. The polarities of the voltages of resistors **36** and **44** are opposite each other. The voltage of resistor **36** referred to as an "operating" voltage, is in the direction to excite tube **37** to conduct and to operate relay **41**. The opposing voltage appearing on resistor **44**, referred to as a "restraining voltage," always tends to hold the grid of tube **37** negative and to prevent firing.

The output of coil **28** also produces a voltage that tends to restrain tube **37**. Coil **28** is connected to the grid of a triode **45** through a resistor **58** and a bias battery **57**. The operation of this part of the system is illustrated in Figure 2. The voltage produced by coil **28** is E_1. This is a wave sinusoidal in general form composed of the fundamental frequency of the line and some harmonics. This voltage, added to the fixed unidirectional voltage of battery **47** produces a voltage E_2 which is impressed on the grid of triode **45**. This voltage is composed mainly of a 60-cycle component if the transmission line **1** is operating, for example, at the usual frequency of 60 cycles per second.

The grid of triode **45** being excited at 60 cycles per second is adjusted to be overdriven so as to produce a rectangular wave output E_3 as shown in Figure 2. This wave is impressed on a low pass filter **46** which extracts the 60-cycle component from the constant amplitude wave E_3, thus producing a constant amplitude 60-cycle wave E_4. The output of filter **46** is impressed on a rectifier **47** which produces a unidirectional wave E_5 composed of 120 rectified sinusoidal pulses per second. E_5 is impressed on the grid of a triode **48**. This rectified sinusoidal signal drives the grid below cut off so that plate current flows for only a portion of each pulse. By adjusting the cathode self-bias voltage on tube **48** the width of output pulses may be varied as desired.

The output E_6 of triode **48** is a series of separated, peaked, triangular-shaped pulses, each having a width at the base of about 45 electrical degrees as shown in Figure 2. These pulses are separated accordingly by spaces about 135 electrical degrees. These pulses are delivered to the grid of a triode **49**. Voltage E_6 is produced initially across a grounded resistor **51**. A condenser **52** transmits pulses of current from resistor **51** to a grounded resistor **53** and the cathode of triode **54** connected to act as a rectifying diode.

Triode **54** has low impedance to potential differences which would make the grid of triode **49** negative and accordingly tends to prevent a negative bias thereon. While a triode tube connected as a diode is shown, this function may be performed by any one of a number of rectification devices well known to the art. This action is characteristic of arrangements called "clamping circuits" in radar technique. The voltage E_6 is made sufficiently large to produce what is referred to as "clipping" in triode **49** thus producing E_7 in the form of flat-topped waves as shown in Figure 2. The plate current of triode **49** produces flat-topped pulses across a resistor **55** to which is connected a bias battery **56**.

The polarity of triode **49** in respect to bias battery **56** is such that the potential difference across resistor **55** adds to the bias voltage E_9 of battery **56** to produce an increased bias voltage on gas triode **37**. The potential difference E_8 is of the same polarity as E_r which appears across resistor **44** and is also referred to as a restraining voltage. E_8, as shown in Figure 2 fills in the time during which E_r becomes momentarily zero, thus producing a voltage E_r+E_8, which under normal conditions always has a value sufficient to prevent tube **37** from firing. This voltage exists to prevent tripping except under fault conditions.

Voltage E_9, also by itself, is sufficient to prevent tube **37** from firing under normal conditions. The added voltages E_r and E_8 together with E_9 produce a bias voltage, restraining tube **37**, so that tube **37** cannot fire unless there is an overpowering positive bias voltage E_{11} produced across resistor **36**. Under conditions of fault in line **1**, E_{11} increases and E_r and E_8 decrease. Under these conditions, if E_{11} becomes sufficiently large, E_r, E_8 and E_9 are all exceeded so that the negative bias voltage on the grid of tube **37** is decreased to the level indicated by the broken line marked "tripping voltage" in Figure 2, thus permitting tube **37** to become conducting and to operate relay **41**.

If, under abnormal but not faulty conditions, triodes **23** and **24** both lose their voltages, E_r and E_8 will vanish. But under these conditions E_{11} also will vanish. This still leaves E_9 to bias the grid of tube **37** and to prevent firing. This is the situation that would exist in case of loss of voltage on line **1** or of failure of radio transmitter **12** or receiver **13**.

Figure 1 shows the installation for operating circuit breaker **7** only. The circuit shown in Figure 1 opens circuit breaker **7** when relay **41** closes. A complete protective relay installation of this kind includes a similar arrangement at the other end of line **1** for operating circuit breaker **6**. The communication channel, to take care of both ends, needs to be a two-way circuit

In Figure 2, the angular values 45 degrees and 135 degrees shown for E_6 are illustrative, but not limiting. The value 45 degrees can be any value in a range of about 30 to 60 degrees for the angular width of the pulses and from 120 to 150 degrees for the angular spacing between pulses. In the system described, it will be apparent that the filling-in effect of E_8 at the zero points of E_r could be accomplished, per se, by a condenser connected across resistor **44**, but this would not be operationally equivalent to the arrangement shown. The condenser if present would hold the voltage under fault, as well as normal conditions for a time of the order of a cycle and this would make the operation of the system slower than is desired. The restraining effect of E_r and E_8 can be dispensed with if desired, but with some sacrifice of flexibility of control and certainty of operation.

We claim:

1. In a transmission line relay system, the combination of a first phase sequence network at one end of a line, a signal transmission system for producing at said one end of said line a voltage proportional to the output of a second phase sequence network located at the other end of said line, transformers receiving respectively said voltage and the output of said first network, coil connections in said transformers such that a sum voltage proportional to the sum of the inputs of the two transformers, and a difference voltage proportional to the difference between said inputs of the transformers is produced, two amplifiers responsive respectively to said sum and difference voltages, rectifiers receiving respectively the alternating components of the outputs of said amplifiers, a series of resistors to which are connected, in opposite polarity, the outputs of said rectifiers, means for adding to said series of resistors a third constant voltage

additive to the voltage produced in said series of resistors by the rectifier connected to the amplifier responsive to said sum voltage, and means for operating a relay when the ratio of the voltage derived in said resistors from said sum and additive voltages to the voltage derived i i said resistors from said difference voltage exceeds a predetermined value.

2. In a transmission line relay system, the combination of means for producing a sum voltage proportional to the sum outputs of phase sequence networks at the two ends of a line, means for producing a difference voltage proportional to the difference between the said outputs, two channels respectively under the control of said sum and difference voltages, each channel containing in sequence, an amplifier, a transformer, and a rectifier, means connecting the outputs of the two rectifiers in opposite polarity to two resistors in series, means for adding to the resistors in series a constant voltage and means for operating a relay when the ratio of voltage produced in said series by said channel under the control of said difference voltage to the sum of the other voltages in said series exceeds a predetermined value.

3. An improved protective relay system for an electric power transmission line comprising means for obtaining two signals responsive to the current at opposite ends of said electric power transmission line; means for comparing the two signals and obtaining sum and difference signals; means for amplifying the said sum and difference signals: an actuating thermionic tube with at least one grid; means for positively biasing the grid of said actuating thermionic tube in proportion to the said difference signal; means for negatively biasing the grid of said relay actuating thermionic tube a predetermined amount; means for full wave rectifying the said sum signal; means for further negatively biasing the grid of said actuating thermionic tube with the full wave rectified sum signal; means for still further negatively biasing the grid of said relay actuating thermionic tube with a signal of roughly square wave form and of frequency twice the fundamental frequency of the current in the said electric power transmission line and of constant amplitude whenever magnitude of said sum signal exceeds a given bias value; means responsive to the plate current in said actuating thermionic tube for opening the said electric power transmission line.

4. In an electrical system of the type comprising relay tube means having a control electrode and a full wave rectifier for rectifying an alternating current and applying the rectified current as bias to said control electrode to control the conductivity of said tube means, a circuit for instantaneously preventing said bias from approaching zero, said circuit comprising means to amplify and limit the magnitude of said alternating current, an electrical filter to extract from said amplified and limited current a constant magnitude fundamental alternating current frequency, a second vacuum tube amplifier, a full wave rectifier to rectify said fundamental frequency and apply negative half waves, equal in number to the number of half waves of the fundamental alternating current frequency, to the grid circuit of said second vacuum tube amplifier properly biased to produce positive peaked unidirectional pulses of approximately 45 electrical degrees duration, and a third vacuum tube amplifier operating in conjunction with a diode clamping circuit to amplify, invert and limit the peaked pulses thereby producing negative, unidirectional, constant magnitude, flat topped narrow pulses of approximately 45 electrical degrees duration so phased as to overlap in time the zero points of said rectified signal and means for applying said pulses in series with said rectified signal to the control electrode of said vacuum tube to instantaneously prevent the bias thereon from approaching zero.

5. Apparatus for protecting a polyphase transmission line carrying current of a given frequency, comprising, in combination, means at each end of the line for generating counterparts of the three phase currents on the line and for combining and deriving a single phase current from said three phase counterparts, a radio link for transmitting the derived single phase current from one end of said line to the other, means at said other end of said line for deriving from the two single phase currents a sum voltage and a difference voltage proportional respectively to the sum and difference between said two single phase currents, means for rectifying said difference voltage to obtain a positive biasing voltage, means for deriving from said sum voltage a train of unidirectional rectangular pulses and a train of unidirectional sinusoidal pulses, means for phasing one of said trains to overlap the rectangular pulses with the zero points of said sinusoidal pulses, means for combining the so overlapped rectangular and sinusoidal pulses into a negative biasing voltage, a relay, relay tube means connected to actuate said relay, said relay tube means comprising a control electrode, means for connecting said positive biasing voltage and said negative biasing voltage to said control electrode, and means for adjusting the magnitudes of said positive and negative biasing voltages to a point at which they hold said relay tube means non-conducting under normal line conditions and render said relay tube means conducting under line fault conditions.

6. In an electrical system of the type comprising relay tube means having a control electrode and a full wave rectifier for rectifying an alternating current and applying the rectified current as bias to said control electrode to control the conductivity of said tube means, a circuit for preventing said grid bias from approaching zero as said rectified full wave approaches zero, said circuit comprising amplifying and limiting means for deriving from said full wave a constant amplitude alternating current component, means for deriving from said constant amplitude component a series of unidirectional pulses phased to overlap the zero points of said constant amplitude component, and means for combining said unidirectional pulses in overlapping relation to the zero points of said bias and with like polarity thereto and for supplying the same to said control electrode to supply biasing potential thereto during the intervals when the bias afforded by said rectified full wave approaches zero.

7. Apparatus according to claim 6, in which said means for deriving unidirectional pulses comprises means for full wave rectifying said constant amplitude component, a circuit containing a source of current, said circuit comprising means responsive to said rectified constant amplitude component to interrupt flow of current from said source except when said rectified component approaches zero value, and means for deriving said series of unidirectional pulses from said interrupted current.

References Cited in the file of this patent

UNITED STATES PATENTS

Re. 19,034	Fitzgerald	Dec. 26, 1933
2,027,214	Wideroe	Jan. 7, 1936
2,183,646	Harder	Dec. 19, 1939
2,213,294	Ward	Sept. 3, 1940
2,275,941	Bostwick	Mar. 10, 1942
2,399,322	Carlin	Apr. 30, 1946
2,406,616	Lensner	Aug. 27, 1946
2,406,617	Lensner	Aug. 27, 1946
2,408,868	Mehring et al.	Aug. 27, 1946
2,462,799	Young et al.	Feb. 22, 1949
2,523,813	Chevallier	Sept. 26, 1950