

Nov. 3, 1970

J. M. CROCKETT

3,538,384

PRODUCT RESPONSIVE RELAY WITH A VARIABLE -Q FILTER

Filed Aug 28, 1967

3 Sheets-Sheet 1

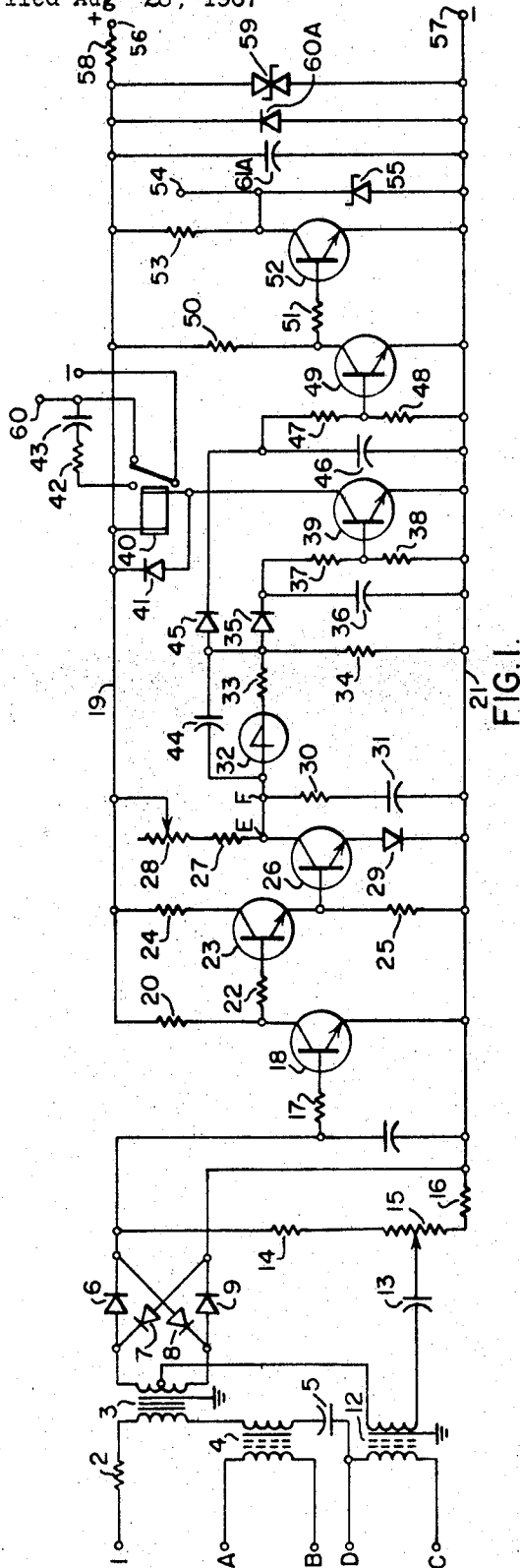


FIG. 1.

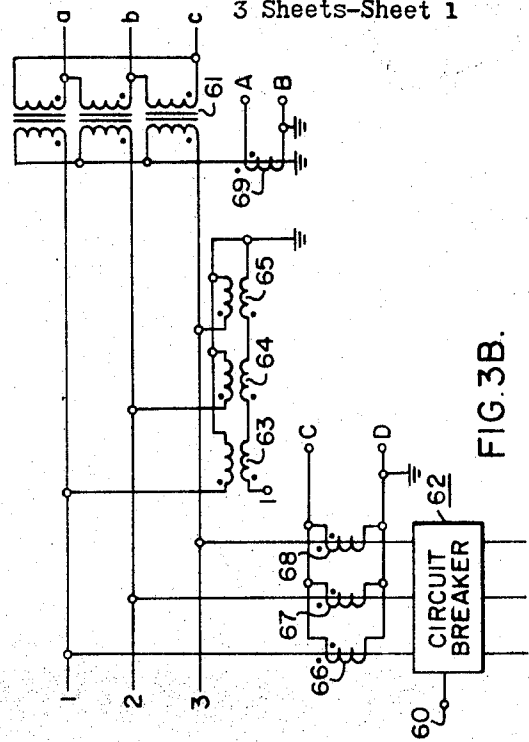


FIG. 3B.

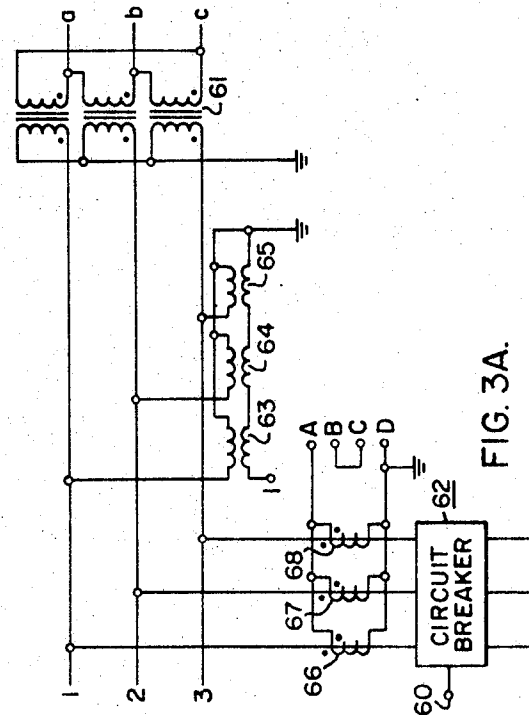


FIG. 3A.

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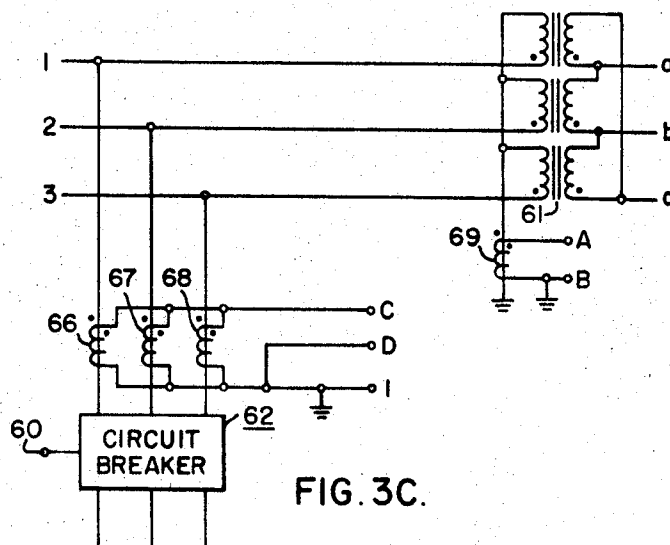
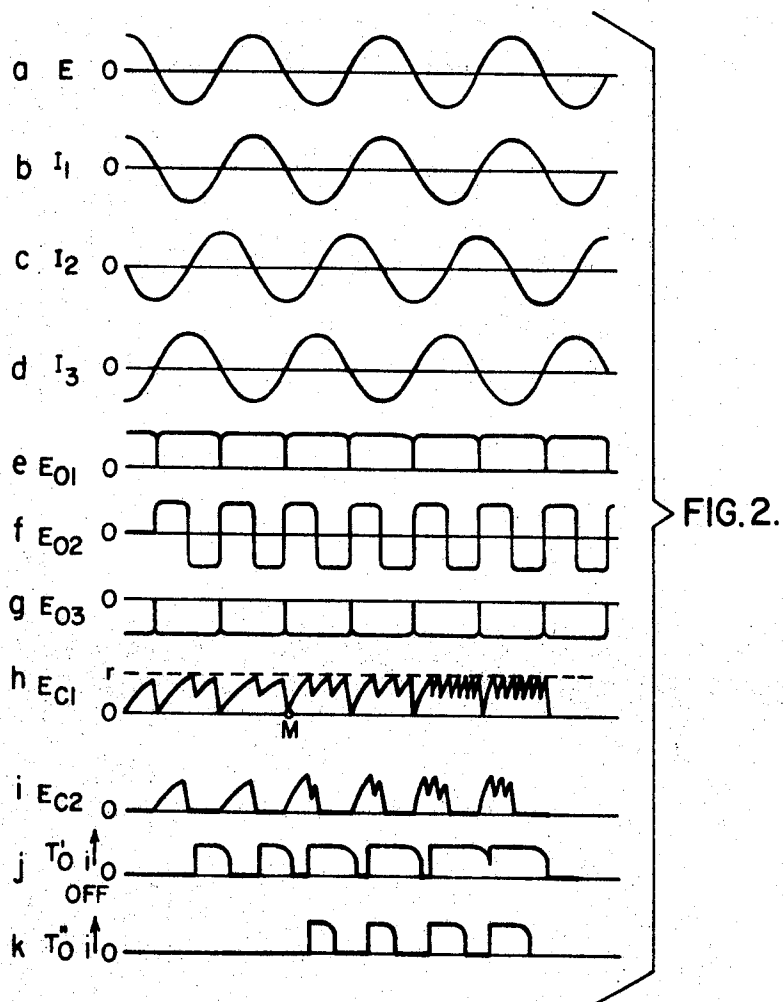
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PRODUCT RESPONSIVE RELAY WITH A VARIABLE -Q FILTER

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3 Sheets-Sheet 3

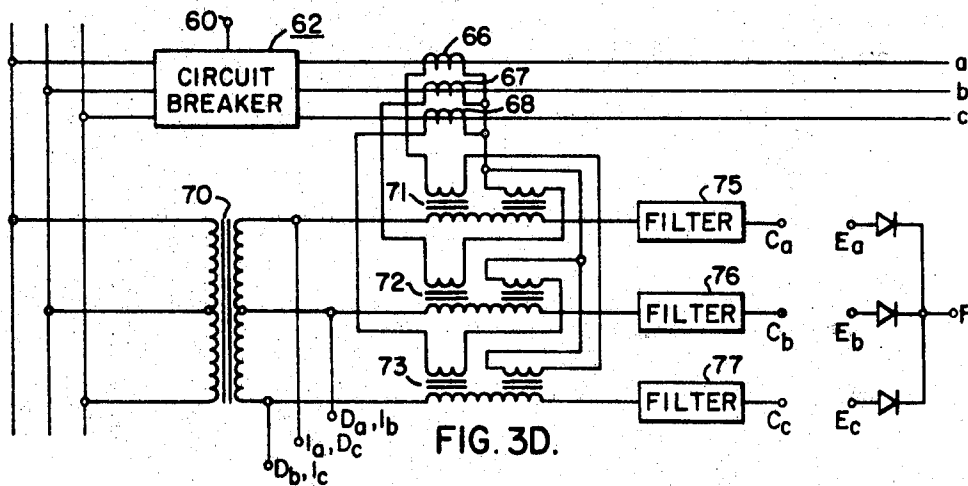


FIG. 3D.

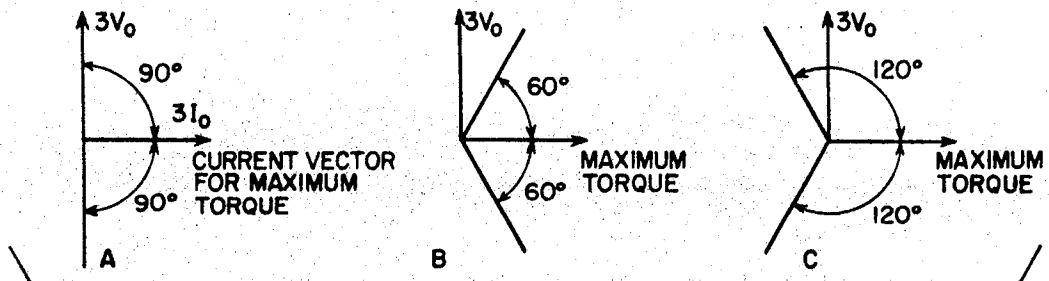


FIG. 4.

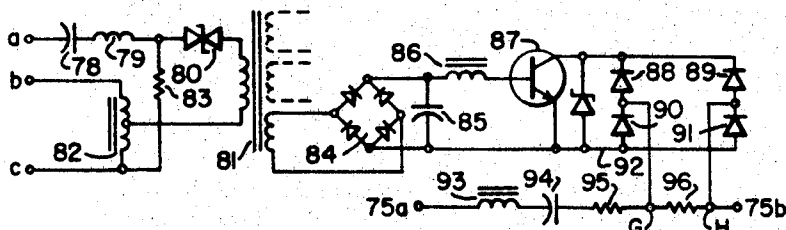


FIG. 5.

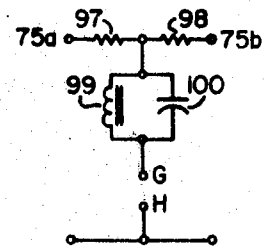


FIG. 6.

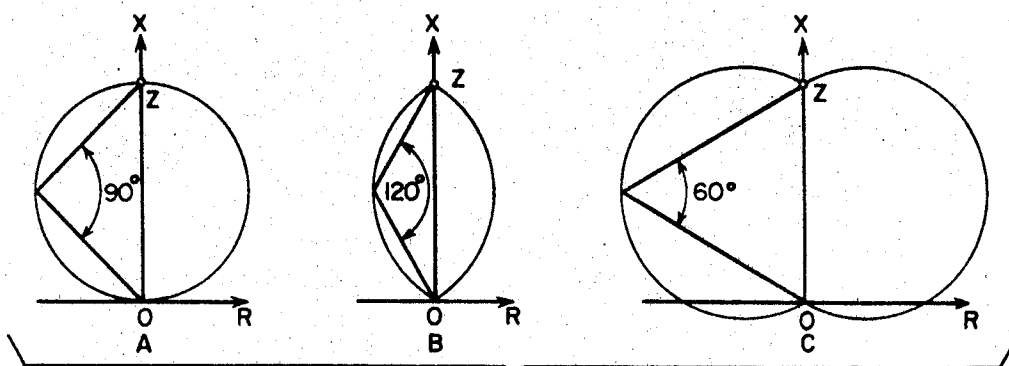


FIG. 7.

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PRODUCT RESPONSIVE RELAY WITH A VARIABLE-Q FILTER

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Filed Aug. 28, 1967, Ser. No. 663,715

Claims priority, application Canada, Oct. 22, 1966,
973,810

Int. Cl. H02h 1/04, 3/28

U.S. Cl. 317-27

4 Claims

ABSTRACT OF THE DISCLOSURE

This disclosure relates to a line protecting relay network which is energized through two input circuits each of which resonate at the line frequency. A ring modulator is provided to render the output sensitive to the phase difference of the signals applied to the two input circuits. The two input signals may be energized by two quantities derived from the line to be protected and the net result used to control the operations of a control circuit of a circuit breaker.

Applicant hereby claims the benefit of the priority of his copending Canadian application Ser. No. 973,810 filed Oct. 22, 1966, for Product Responsive Relay.

This invention relates to relays and in particular to relays which are responsive to the product of two quantities.

Under various conditions it is advantageous to utilize a relay which is responsive not only to a single quantity but in fact to the algebraic result of the multiplication of two quantities, including their phase angle. Relays of this type have a particular application in ground detection and distance relaying. Various relays of this type have been proposed in the past including induction disc and induction loop or cylinder relays. With the increase in speed of operation of various elements in power systems, it has been necessary to increase the speed of operation of relays. The trend therefore recently has been toward the utilization of semiconductor devices to combine various signals and the ultimately control the contacts of a device such as a circuit breaker.

When such semiconductor devices are used in the control circuitry and the circuitry is arranged for rapid response there is always the danger that the relay may respond to transients which do not represent an actual condition to be sensed. Elimination of such transients by means of filters, however, may give rise to time delays which are characteristic of filters which may or may not be objectionable under the circumstances.

Since most power systems are three phase, it is also desirable that the signal should be applicable from all three phases to as much of the common circuitry as possible in order to eliminate redundancy and multiplicity of apparatus.

In accordance with the present invention, the foregoing problems of the prior art are overcome by providing resonant circuits in the input which resonate at the frequency of the power system, thus substantially eliminating transients. At the same time the filters used in the relay may be switched so that they are only operative during the period when a fault may occur. In this way the time delays introduced by the filter are minimized. The quantities to be combined are applied to a ring modulator otherwise known as a diode phase comparator which combines the two input signals and produces an output depending upon the amplitude and phase angle of the inputs. The output from the phase comparator is

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applied to a semiconducting circuit which evaluates the product of the input signals for each half cycle and controls a contacting type output relay and/or a semiconductor voltage output circuit to produce outputs which may be used in various ways to control the power system.

A clearer understanding of my invention may be had from the following description and drawings, in which:

FIG. 1 is a schematic diagram of a relay in accordance with my invention.

FIG. 2 is a series of waveform diagrams useful in explaining the operation of such a relay.

FIG. 3A is a power system arranged to provide the necessary signals to the relay for detecting ground faults as a ground directional relay with zero sequence current compensation.

FIG. 3B similarly is arranged to provide the necessary signals to the relay to permit it to operate as a dual-polarized ground directional relay.

FIG. 3C shows a power system arranged to supply the necessary signals to the relay to operate the relay as a current polarized relay.

FIG. 3D shows a power system arranged to provide the necessary signals to permit operation of the relay as a directional relay.

FIG. 4 is a series of relay characteristics arranged to illustrate three possible modes of operation of the relay as a ground directional relay.

FIG. 5 is one possible arrangement of the switch filter circuit.

FIG. 6 is a further possible arrangement of a switch filter circuit, and

FIG. 7 is a series of RX diagrams representing three possible characteristics of the relay operating as a distance relay.

Considering first FIG. 1, it will be seen that one input terminal designated 1 is connected through resistor 2, transformer primary 3, the secondary of mutual reactor 4, and capacitor 5 to terminal D. Diodes 6, 7, 8 and 9 are arranged as a ring modulator. One end of the centre tapped secondary of transformer 3 is connected to the junction of diodes 6 and 7 and the other to the junction of diodes 8 and 9. Terminals C and D are connected to the primary of mutual reactor 12 and the secondary of this reactor 12 is connected at one end to centre tap of the secondary of transformer 3 and at the other end through capacitor 13 to an adjustable point on a potentiometer consisting of resistors 14, 15 and 16 in series between the junctions of diodes 6 and 8 and 7 and 9. The output from this phase comparator is applied through resistor 17 between the base and emitter of transistor 18. The collector of transistor 18 is connected to the positive supply line 19 through resistor 20 and the emitter of transistor 18 is connected to the negative supply line 21. The collector of transistor 18 is also connected through the resistor 22 to the base of transistor 23. The collector of transistor 23 is connected through resistor 24 to the positive supply line 19. The emitter of transistor 23 is connected through resistor 25 to the negative supply line 21. The emitter of transistor 23 is also directly connected to the base of transistor 26. The collector of transistor 26 is connected through resistor 27 and variable resistor 28 to the positive supply line 19. The emitter of transistor 26 is connected to the negative supply line through diode 29. The collector of transistor 26 is also connected through resistor 30 to capacitor 31; the other terminal of this capacitor being connected to the negative supply line 21. The collector of transistor 26 is also connected through Shockley diode 32 and resistor 33 and resistor 34 to the negative supply line 21. The junction of resistors 33 and 34 is connected through diode 35 and capacitor 36 to the negative supply line 21. The

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junction of diode 35 and capacitor 36 is connected through resistors 37 and 38 to the negative supply line. The junction of resistors 37 and 38 is connected to the base of transistor 39. The emitter of transistor 39 is connected to the negative supply line 21, and the collector is connected through the coil of relay 40 to the positive supply line 19.

Diode 41 is connected across the coil of relay 40. The contacts of relay 40 consists of a single pole double throw switch of the type referred to as make before break. The stationary contacts of this relay are connected together through a protective circuit comprising resistor 42 and capacitor 43.

Capacitor 44 is connected across diode 32 and resistor 33 and the junction of this capacitor and resistor 33 is connected through diode 45 to the negative supply line through capacitor 46. The junction of diode 45 and capacitor 46 is connected to the negative supply line through resistors 47 and 48. The junction of resistors 47 and 48 is connected to the base of transistor 49. The emitter of transistor 49 is connected to the negative supply line 21 and a collector is connected through resistor 50 to the positive supply line 19. The collector is also connected through resistor 51 to the base of transistor 52. The emitter of transistor 52 is connected to ground and the collector is connected through resistor 53 to the positive supply line 19. The collector of transistor 52 is connected to the output terminal 54 which terminal is also connected to the negative supply line through Zener diode 55.

Supply for the semiconductor circuitry is provided from the positive and negative terminals 56 and 57 respectively, terminal 57 being connected directly to the negative supply line and terminal 56 being connected through resistor 58 to the positive supply line 19. Zener diode 59 and protective diode 60 and capacitor 61 are all connected between the positive supply line 19 and the negative supply line 21.

OPERATION

The inductance provided by the primary winding of the transformer 3 and the secondary winding of the mutual reactor 4 together with the capacitance of capacitor 5 form a resonant circuit resonant at 60 cycles or the normal frequency of supply. In a similar manner the inductance provided by the secondary winding of the reactor 12 together with the capacity of capacitor 13 form a series resonant circuit resonant at 60 cycles. Because both of these circuits are resonant at the supply frequency they are relatively immune to spurious responses due to transients. Since the elements between terminals 1 and 0 represent a series resonant circuit the currents between terminals 1 and 0 will be a maximum at resonance and therefore the output from the secondary of transformer 3 will be a maximum at the resonant frequency of the series circuit. Similarly the current provided by the secondary of transformer mutual reactor 12 will be a maximum at its resonant frequency.

As has been previously indicated, diodes 6, 7, 8 and 9 are arranged as a ring modulator or phase detector and arranged so that when the two input currents applied by the secondary of transformer 3 and that applied by the secondary of mutual reactor 12 are of the same instantaneous polarity, the junction point of diodes 6 and 8 becomes positive with respect to the junction point of diodes 7 and 9, thus applying a positive potential through resistor 17 to the base of transistor 18 and causing transistor 18 to be turned on. On the other hand, when the two input currents are not of the same instantaneous polarity or if either input is zero the output voltage will be negative or zero and transistor 18 will be turned off.

With transistor 18 turned on, its collector is effectively connected to the negative supply line thus switching off transistor 23 which in turn switches off transistor 26. With transistor 26 switched off its collector is essentially

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at the positive supply line potential, except for any resistance drop through resistors 27 and 28, and the capacitor 31 charges through resistor 28, resistor 27 and resistor 30. If the resulting potential at the collector of transistor 26 reaches a set value the diode 32, which is a Shockley diode, breaks down and the charge stored in capacitor 31 is transferred through resistor 33, and diode 35 to capacitor 36 and also through resistor 33 and diode 45 to capacitor 46. Since the potential which determines breakdown is the potential across the Shockley diode 32 it is necessary to the satisfactory operation of the circuit that the potential across the Shockley diode be the potential at the collector of transistor 26 with reference to ground. Diodes 35 and 45 create the necessary isolation between the subsequent circuit and the Shockley diode, so that potentials on capacitors 36 and 46 cannot appear at the junction of resistor 33 and 34.

When capacitor 36 is charged, it raises the potential applied to the potentiometer consisting of resistors 37 and 38 thus raising the base of transistor 39 to a positive potential causing this transistor to switch on and a current to flow through the control winding of relay 40.

In a similar manner the potential on capacitor 46 is applied to the potentiometer consisting of resistors 47 and 48 causing the base of transistor 49 to become positive thus switching on this transistor. When the transistor 49 becomes conductive its collector is effectively connected to the negative supply line causing the base of transistor 52 to be negative thus switching off transistor 52 and raising the potential of its collector to the positive supply line potential and producing a positive potential on terminal 54. An output can be derived from the circuit either from the contacts of relay 40 or from the terminal 54 depending upon the subsequent apparatus to be controlled. As shown in the diagram, the relay 40 is deenergized, the normally open contacts are open and this de-energizes the trip circuit for the circuit breaker.

There are two adjustments in the circuit for determining its point of operation, the first adjustment is on the adjustable resistor 15 which is set up to provide the proper balance of the phase detector circuit to ensure that under zero input conditions there is zero output. With a current provided from the secondary of mutual reactor 12 and no input provided from the secondary transformer 3, for example, there should be no output across the terminals of the ring modulator.

The second adjustment has to do with the charging of capacitor 31. It will be noted that the charging circuit of this capacitor includes resistor 28 which is adjustable. Since the Shockley diode breaks down when capacitor 31 reaches a particular potential, it will be seen that the operation of the relay is dependent upon the length of time required for capacitor 31 to arrive at a particular potential. By adjustment of resistor 28 the rate of charge of capacitor 31 can be adjusted. At the same time, in order to avoid improper operation when a series of breakdowns of the Shockley diode occur causing charging of capacitor 36 and 46, it is necessary to ensure that the Shockley diode 32 continues to operate based upon the potential between the collector of transistor 26 and ground. As was previously indicated, diodes 35 and 45 perform the function of isolating capacitors 36 and 46 from the Shockley diode. Resistor 34 connects the junction of the diodes 35 and 45 and resistor 33 to ground, the resistance of resistor 34 is much less than the back resistance of the diodes 35 and 45; therefore this point effectively connected to ground and the potential effective across the Shockley diode 32 is the potential between the collector of transistor 26 and ground. By adjustment of resistor 28 therefore, the characteristic of the relay may be adjusted, determining the length of time transistor 18 must be switched on before the relay operates and this in turn determining the necessary phase angle difference between the currents supplied to the ring

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modulator from the two different sources in order to produce relay operation.

Considering now FIG. 2, there is shown at *a* a graph of voltage versus time of the power system. This graph will be used as a reference for the remaining waveforms illustrated. Waveform *b* illustrates a current waveform in phase with the voltage waveform shown at *a* which might occur in one of the phases or in the ground return of the current transformers and be used to provide one of the inputs to the ring modulator. Assuming that the waveform shown at *a* is used as the primary input to the modulator, waveform *c* is a further current waveform which might be used as the second input to the ring modulator having a phase difference of 90° with respect to waveform *a*. This waveform might be provided to the ring modulator under various circumstances. Waveform *d* is a yet further current waveform which might be applied to the ring modulator under other circumstances where the current is 180° out of phase with the reference voltage shown at *a*. Waveform *e* shows the output voltage from the ring modulator which is applied to the base of transistor 18 when the input waveforms are as shown at *a* and *b*. It will be noted that the ring modulator produces a substantially constant output until one or both of the waveforms approach zero, this results in a substantially constant output voltage with spikes projecting down to the zero line. Waveform *f* shows the output from the ring modulator when waveforms as shown at *a* and *c* are applied as an input. It will be noted that a substantially constant output pulse is produced while waveforms *a* and *c* are either both in the negative direction or both in the positive direction and that a substantially constant negative going pulse is produced when the waveform at *a* is in a positive direction and the waveform at *c* is in the negative direction or conversely when the waveform at *c* is in the positive direction and the waveform at *a* is in the negative direction. The waveform at *g* represents the output from the ring modulator when waveforms *a* and *d* are used as inputs to the ring modulator and it will be noted it consists of a series of negative going pulses of substantially constant amplitude with intervening spikes going up to the zero line where one or both of the waveforms approaches zero.

Since transistor 18 becomes conductive only when the applied waveform goes in a positive direction the output from transistor 18 will be similar to the waveform shown at *e*, *f* and *g*, except that it will be clipped and not have any excursions in the negative direction. As a result, waveform *g* ceases to exist, in effect, since no values below the zero line are reproduced in the output of transistor 18 and the waveform *f* is clipped at the zero line. The waveform at *h* shows the potential at the collector of transistor 26 when the waveform *e* is applied to the base of transistor 18. As soon as transistor 18 is turned on, transistor 26 is turned off, and capacitor 31 begins charging through resistors 28, 27 and 30. As was previously indicated the rate of charge is determined by the setting of variable resistor 28. The capacitor starts to charge but before it reaches the reference line *r* the waveform goes to zero, transistor 18 switches off, transistor 26 switches on and the capacitor is discharged down to the zero line. In the next cycle, the capacitor begins to charge when transistor 26 is switched off and rises until the voltage on the collector of transistor 26 reaches the reference line *r* at which point Shockley diode 32 begins conducting and a portion of the charge on capacitor 31 is transferred through resistor 30, resistor 33, diode 35 to capacitor 36 thus reducing the voltage on capacitor 31. Transistor 26, however, remains cut off and the charging continues up the second charging curve until transistor 18 is once more switched off, transistor 26 is switched on and the capacitor 31 is discharged.

The next waveform shown at *h* indicates what occurs when resistor 28 is reduced in value. Referring to the waveform that starts at point M at waveform *h* it will be

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seen that the slope of the curve is much steeper because resistor 28 is less. The reference line is therefore reached earlier in time. Shockley diode 32 breaks down and capacitors 31 and 36 start to recharge, after the voltage is first reduced due to the transfer of charge from capacitor 31 to 36. The voltage at the collector of 26 once more rises to the reference line and it will be noted that because of the presence of the isolating diode 35, the potential across the Shockley diode 32 is, as was previously indicated, effectively the potential between the collector of transistor 26 and ground. The Shockley diode therefore once again breaks down and further charge is transferred from capacitor 31 to capacitor 36. Capacitor 31 then once again begins to recharge until either transistor 26 becomes conductive or the Shockley diode breaks down whichever occurs first.

As illustrated, it is assumed that the transistor 26 once more becomes conductive because the waveform *e* has once more gone to zero, this causes the capacitor 31 to be completely discharged and the cycle begins over again. If resistor 28 is decreased still further then the rate of charging of capacitor 31 increases as shown in the latter two waveforms illustrated at *h*. The operation does not differ from that previously described except, that the rate of charging being of greater, the voltage arrives at the reference level *r* in a lesser time causing a greater series of breakdowns of the Shockley diode and transfers of energy from capacitor 31 to capacitor 36. It should be understood when reference is made to transfer of energy from capacitor 31 to capacitor 36 there is simultaneously occurring a transfer of energy from capacitor 31 to capacitor 46 through resistor 33 and diode 45.

Considering now waveform *i* of FIG. 2, this waveform is the waveform of the voltage at the collector of transistor 26 when the waveform *f* is applied to the base of transistor 18. It will be seen that nothing occurs until the waveform at *f* goes positive causing transistor 18 to become conductive and transistor 26 cut off. At this point the capacitor 31 begins to charge and let us assume that it charges at the same rate as it did in waveform *h*, that is, resistor 28 has been set to the same position as it was in the first three waveforms of waveform *h*. It will be seen, that the potential at the collector of transistor 26 never reaches the breakdown potential of the Shockley diode 32 and the capacitor therefore goes on charging until transistor 26 becomes conductive causing it to discharge at the end of the positive waveform *f*. Capacitor 31 remains discharged until waveform *f* once more goes positive at which point it once more begins to charge but again does not ever reach the breakdown potential of the Shockley diode and no further effect occurs. At the next waveform, however, it has been assumed that the resistor 28 has been reduced in value as it was with reference to waveform *h*. It will be noticed now that the rate of charge of capacitor 31 increases and the potential at the collector of transistor 26 rises at a greater rate and reaches the reference line *r* at which point the Shockley diode 32 breaks down causing a transfer of energy to capacitor 36 through resistor 33 and diode 35. Capacitor 31 now begins to recharge and before it reaches the reference line *r*, transistor 18 becomes non-conductive because the waveform *f* assumes a negative polarity, transistor 26 becomes conductive and capacitor 31 is discharged. This cycle is once more repeated when the waveform *f* assumes a positive potential. When, as shown in the latter waveforms of waveform *h*, the resistor is reduced still farther capacitor 31 charges at a greater rate, the potential rises more rapidly until it reaches the reference line *r* at which point the Shockley diode 32 breaks down permitting transfer of part of the energy from capacitor 31 to capacitor 36. Capacitor 31 commences to recharge once more and again reaches the reference line *r* at which point Shockley diode 32 breaks down and transfer a further charge to capacitor 36. Capacitor 31 again commences to recharge but before it reaches the reference line waveform *f* goes

negative causing transistor 18 to become non-conductive and transistor 26 to become conductive. This cycle is repeated when waveform *f* once more goes in the positive direction.

The waveform at *j* shows the periods of conductivity of transistor 39 or 49 since both obey substantially the same law. Waveform *j* is particularly referred to waveform *h* and as will be seen transistor 39 remains non-conductive until waveform *h* reaches the reference line *r*, at which point the charge transferred to capacitor 36 causes transistor 39 to become conductive. The charge on capacitor 36 maintains the transistor 39 conductive until capacitor 36 is sufficiently discharged through resistors 37 and 38 to permit the base of transistor 39 to approach the potential of the negative bus 21. This same event occurs in the second waveform. In the third waveform, however, it will be noted that two charges are transferred from the capacitor 31 to capacitor 36 and the discharge does not begin to occur until after the end of the second transfer. After this point the capacitor 36 gradually discharges and transistor 39 eventually becomes non-conductive and does not conduct again until a further charge is transferred from capacitor 31 to capacitor 36 in response to breakdown of the Shockley diode 32.

When the value of resistor 28 is still further reduced the rate of charge of capacitor 31 is increased and the number of charges transferred from 31 to 36 is increased and as shown in the latter waveforms the capacitor 36 does not begin to discharge until the last charge is transferred and therefore transistor 39 remains conductive the majority of the time with only a slight period occurring when transistor 39 is not conducting. Waveform *k* is similar to waveform *j* but with particular reference to waveform *i*. It will be seen that the conductivity of transistor 39 remains a minimum until the third waveform of waveform *i*, at which point the waveform for the first time touches the reference line *r* causing a transfer of energy from capacitor 31 to capacitor 36. Energy as before causes the base of transistor 39 to go positive and remain positive until the charge is dissipated through resistors 37 and 38. Transistor 39 therefore remains conductive for a limited period of time and once more becomes conductive when again the waveform *i* touches the reference line *r*. When the resistor 28 is reduced still further the waveform *i* reaches the reference line sooner, transistor 39 becomes conductive at a point earlier in time and remains conductive for a greater proportion of the cycle as is shown in the latter two cycles of waveform *k*.

From all the foregoing it will be apparent that by selection of the various resistors and capacitors the transistor 39 may be maintained conductive for various portions of the cycle depending upon the waveform applied to the base of transistor 18 and in turn relay 40 may be made operative depending upon its own characteristic and held in depending upon the normal delays inherent in the relay, in response to any given waveform input to transistor 18. By adjustment of resistor 28 the effect of an input waveform to transistor 18 may be adjusted so that the relay may be caused to hold or drop out in response to a particular waveform applied to the base of transistor 18 which is equivalent to saying that the relay may hold in or drop out in response to a particular phase relationship between the signals applied to the ring modulator. As will be seen from waveforms *j* and *k* a circuit arranged so that the relay 40 will just hold in response to waveforms of the type shown in the first two cycles of waveform *j* and the last two cycles of waveform *k* and will remain held in response to the other forms of cycles shown in the latter part of waveform *j* but will drop out for the waveforms shown in the earlier portion of waveform *k*. The waveforms shown at *j* and *k* will also appear in inverted form at terminal 54 and may be used to con-

trol some further apparatus or create some further indication of condition of relay.

The time required for capacitor 31 to be charged to the breakdown potential of Shockley diode 32, is of course a function of the potentials applied to resistor adjuster 28. This time may be called alpha and expressed as electrical degrees wherein a 60 cycle system, 360° is equivalent to 16.66 milliseconds. Bearing this in mind and considering FIG. 4, the diagram at A in FIG. 4 illustrates the situation where alpha is adjusted to 90°. The vertical vector represents $3V_0$ or the zero sequence voltage. The relay has been designed to operate with a maximum duration of pulses applied to the base of transistor 18 when the applied current lags the voltage by 90°. Therefore the vector in a horizontal direction pointing in the right represents $3I_0$ for a maximum pulse duration applied to the base of the transistor 18. Under these circumstances the relay will operate if the current vector falls anywhere within plus or minus 90° of the minus $3I_0$ line or the horizontal vector. By different adjustment of resistor 28, alpha may be made equal to 120° that is the charging time will be approximately 5.555 milliseconds and the relay will operate if the current lies within plus or minus 60° of the horizontal vector. As shown at C in FIG. 4, alpha may alternatively be adjusted to 60° and under these circumstances the relay will operate if less than current vector lies within plus or minus 120° of the horizontal vector. As will be apparent, various adjustments of the value alpha may be made to adapt the relay to the particular application.

FIGS. 3A, 3B, 3C and 3D illustrate the various arrangements for utilizing this relay for different functions. Considering FIG. 3A first, this illustrates the necessary circuit arrangement for utilization of this relay as a ground directional relay with potential polarization and zero sequence current compensation. As will be seen, power is supplied from three phases *a*, *b* and *c* to the primary of a three phase transformer 61 with the primary connected in delta. The secondary of the transformer is connected in star and the star point connected to ground. The output from the secondary of this transformer is connected to a load through circuit breaker 62. The potentials on the various phases on the secondary of transformer 61 are combined potential transformers 63, 64 and 65 which are connected in star across the phases *a*, *b* and *c* respectively, with their star points connected to ground. Their secondaries are connected in series to terminal 1. The currents to the load are derived by current transformers 66, 67 and 68 and the zero sequence derived by joining the terminals of the current transformers together at the star point D which is grounded and at the point A. Correspondingly designated terminals are connected together between FIG. 3A and FIG. 1.

As will be seen the first voltage applied to the ring modulator is applied to terminal 1 and polarizes the relay by providing a reference voltage. The zero sequence current derived from the current transformers passes through, the primary of mutual inductor 4 from terminal A to terminal B. Terminal B is connected to terminal C and the same current passes through the primary of mutual inductor 12, to terminal D. The output from the secondary of mutual inductor 12 provides the second input to the ring modulator and the zero sequence current therefore is compared in phase with the reference voltage. At the same time a voltage proportional to the zero sequence current is applied in series with the reference voltage to compensate for the insensitivity which would be caused by low source impedance and low fault current.

FIG. 3B illustrates the arrangement for providing both voltage and current polarization. As before, three buses *a*, *b* and *c* provide the current to transformer 61 and the secondary of this transformer is connected in star with its star point grounded. The current from the star point to ground, however, is passed through a current transformer 69 and the output of this current transformer applied to

terminals A and B. The voltage for polarization is derived as before from the potentials of the three phases through potential transformers 63, 64 and 65 and the zero sequence current flows from terminal C to terminal D to ground. The operation is similar to the operation described for FIG. A and the phase of the zero sequence current is compared with the phase of the combined effect of the potential provided to the ring modulator from the potential transformers 63, 64 and 65 and the current applied in series from the current transformer 69.

FIG. 3C illustrates an arrangement similar to the preceding arrangements where only current polarization is provided. The current from the current transformer 69 is applied to terminals A and B and the zero sequence current from terminal C to ground is applied to terminals C and D, and the phase relationship of those two currents is measured.

FIG. 3D illustrates the circuit arrangement for operation of a group of three of these relays for distance relaying. As before, the three buses are designated *a*, *b* and *c* and are supplied through a circuit breaker 62 and the current from the circuit breaker to the load passes through current transformers 66, 67 and 68. In order for a suitable signal to be provided through the relays, it is necessary to combine several factors, for example, one relay must respond to the potential between buses *a*, *b* and *c*. To this end a potential transformer is provided designated 70 which is connected to the three phases and a voltage is derived from the secondary of this transformer such that the potential between buses *a* and *b* corresponds to the potential between terminals designated 1*a* and 1*b*. This potential may be applied to terminals 1 and D of the relay to provide the voltage polarization or reference voltage for the ring modulator. The other signal to be provided is a function not only of the potential between phases *a* and *b*, but also the current in phase *a* and the current in phase *b*. To this end, mutual reactors 71, 72 and 73 are provided and mutual reactor 71 provides a signal representative of the current from current transformer 66 which is introduced into one primary of the mutual reactor 71 and also the current in phase *b* from current transformer 67 which is introduced into the second primary of mutual reactor 71 in a subtractive manner so that the output from mutual reactor 71 in its secondary represents the current in phase *a* minus the current in phase *b*. In a similar manner the output from mutual reactor 72 is a function of the current in phase *b* minus the current in phase *c* and the output from mutual reactor 73 is a function of the current in phase *c* minus the current in phase *a*. The potential across terminals C_a and D_a therefore may be expressed as the potential between phase *a* and phase *b* minus the current difference between these two phases times some function.

Between the secondary of mutual reactor 71 and terminal C_a there is introduced a filter designated 75 which shall be referred to as a switched filter circuit. Similar devices 76 and 77 are introduced between the secondaries of mutual reactor 72 and terminal C_b and the secondary of mutual reactor 73 and terminal C_c. The operation of these elements will be described in conjunction with FIGS. 5 and 6, but generally it may be assumed that these devices operate to select the desired operating frequency and reject transients but are operative only under certain circumstances.

If terminal C_a is now connected to terminal C of FIG. 1 and terminal D_a is connected to terminal D of FIG. 1 and terminal 1*a* is connected to terminal 1 of FIG. 1, then relay is provided with suitable signals for distance relaying. In order to combine the output from three such relays, that is one for each phase, it is possible to utilize a separate ring modulator for each phase and separate charging circuits and then combine the outputs at a later point in the circuit. To this end, the circuits may be open between points E and F in FIG. 1 and terminal F of FIG. 3D connected to terminal F in FIG. 1, and

the E terminal of the *a* relay connected to terminal E_a in FIG. 3D. In a similar manner the E terminal of the *b* relay will be connected to E_b of FIG. 3D and the E terminal of the *c* relay will be connected to E_c of FIG. 3D. The common latter portion of the relay, that is the elements after terminal F may then be used as a common output for all three phases and the output from terminal 60 of this combined relay may be applied to terminal 60 of FIG. 3D to control the circuit breaker 62.

When operating in this mode the secondary mutual reactor 12 and capacitor 13 do not combine to produce a resonant circuit because such a resonant circuit would produce undesirable delays. In fact capacitor 13 may be omitted. The selective function performed by this tuned circuit in previous modes of operation is performed in this circumstance by switched filters 75, 76 and 77 which are more completely described in association with FIGS. 5 and 6. In order to better appreciate the problem, it should first be considered what the signal across terminals C_a and D_a presents. In fact it is the voltage across phases A and B minus a function times the difference between the currents in phases A and B. Under normal operating conditions the latter part of this function will be essentially zero and the voltage across phases A and B will be a constant therefore if this signal is applied to a filter, the filter will be energized and will have stored a certain amount of energy. If now a fault occurs, the factor proportional to the difference between the current and phase A and current in phase B must reverse in direction and the amount of energy available in this reverse direction depends upon the magnitude of the fault current and the fault location. It will therefore be apparent in order that the relay may detect small fault currents or distant faults, the potential across terminals C and D must be enabled to change rapidly and it must not be necessary to first dissipate the energy of the filter. To this end the filters 75, 76 and 77 are switched and are operative only after a fault occurs. Means of obtaining this end is shown in FIGS. 5 and 6.

Considering first FIG. 5 there will be seen three terminals which are indicated as being connected to phases *a*, *b* and *c*. The *a* terminal is connected through capacitor 78 and inductor 79 and a double anode Zener 80 to one end of the primary transformer 81. Phases *b* and *c* are connected to centre tapped reactor 82. Phase *c* is also connected through resistor 83 to the junction of reactor 79 and Zener 80. The centre tap of the reactor 82 is connected to the remaining terminal at the primary of transformer 81. Primary 81 has three secondaries, one for each phase to be controlled. Those not actually being described are shown in dotted lines. The secondary actually being used in the circuit is connected to a bridge rectifier 84 and the DC output from this bridge is applied to capacitor 85 and through reactor 86 to the base of transistor 87. Four diodes 88, 89, 90 and 91 are arranged in a bridge. The anodes of diodes 88 and 89 are connected together and are connected to the collector of transistor 87. The cathodes of diodes 90 and 91 are connected together and connected to the conductor 92 which is also connected to the emitter of transistor 87 and the negative terminal of rectifier bridge 84. A series tuned filter comprising inductor 93 and capacitor 94 and including two resistors 95 and 96 is connected between terminals 75*a* and 75*b*. It will be understood that terminals 75*a* and 75*b* represent the terminals of filter 75 in FIG. 3D. Components 93, 94 and 95 are chosen to provide the desired filter effect whereas resistor 96 is sufficient to lower the "Q" of the resonant circuit to such a degree that very little energy is stored in the filter. The operation of this circuit may be explained as follows.

With a fault on the system, negative sequence current flows causing a current from phase *a* to flow through the primary of transformer 81 to the center tap of reactor 82. The components are so chosen that when a normal positive sequence voltage is applied to terminals *a*, *b* and *c*

there is no input to transformer 81. However, when negative sequence current occurs due to a fault there is an input to transformer 81. Because transients may under some circumstances not be present, capacitor 78 and conductor 79 are included to ensure that there are reactive components present at all times to energize transformer 81. The double anode Zener 80 limits the signal applied to the transformer 81. The output from the transformer is applied through bridge 84 to capacitor 85 which stores the output together with reactor 86 to ensure that once a signal is produced it remains on the base of transistor 87 for an appreciable length of time, for example, something in the order of 100 milliseconds. As long as transistor 87 is conductive, terminals G and H are in effect shorted together thus eliminating resistor 96 from the circuit. Under these circumstances the filter is effective and if tuned to resonate at the network frequency eliminates transients. Since as was previously indicated the filter is effective only during a fault, no energy is stored previous to the commencement of the fault. In this way the advantages of filtering are obtained without the concurrent disadvantage of delays caused by energy storage within the filter. FIG. 6 shows an alternative arrangement including resistors 97 and 98 and a parallel tuned filter comprising inductor 99 and capacitor 100. Terminals G and H from the previous circuit, that is from the bridge comprising diodes 88 to 91 are connected in series with the parallel tuned circuit. With terminals G and H open circuited, the tuned circuit which is resonated at the system frequency is not operative and therefore no energy is stored in it. However, when a fault occurs and terminals G and H are short circuited, the parallel tuned circuit becomes effective responding selectively to the normal system frequency and eliminating transients from the signal. As before, the terminals of this filter are designated 75A and 75B and represent the terminals of filter 75 in FIG. 3D.

All of the advantages previously noted with reference to this relay are equally applicable to these applications and it will be noted for example with reference to FIG. 3D that the output from terminal 1_a is applied to the primary of mutual reactor 3 and as before this is a tuned resonant circuit which responds with greater sensitivity to signals of the supply frequency than to signals of the supply frequency than to signals of other frequency and the common output described in association with FIG. 3D minimizes the number of elements required to perform the desired function.

It will be appreciated that the relay as described may also be applicable in other situations and that various substitutions may be made for various elements as described in FIG. 5 could be replaced by a mechanical switch provided the mechanical switch had a sufficiently high operating speed. Even in this case, however, it would seem advisable to utilize the negative sequence current as the actuating signal for controlling relay.

As was previously indicated, FIG. 7 at A, B and C illustrates three possible RX characteristics obtainable by varying alpha the time setting of the relay. When alpha is adjusted to 90° the conventional mho characteristic is

obtained. The line OZ represents the relay setting and subtends an angle at the circumference of the characteristic equal to the angle alpha. With alpha adjusted to 120° as illustrated at B of FIG. 7 the operating characteristic is restricted which limits the probability of the relay operating on power swings and may be particularly useful on long lines. At C there is illustrated a characteristic where alpha is less than 90°, for example, 60° and the operating characteristic is enlarged. Such a characteristic, from its greater tolerance to fault resistance, has particular utility on short lines. It will be evident that other intermediate values may be utilized where advantageous.

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

1. In a fault sensing relay for an alternating potential electric power transmission line, a phase discriminator having first and second inputs and an output, supply means effective to supply first and second electrical quantities individually to said first and second inputs respectively, the phase angle of one of said quantities being dependent upon the operating condition of said line, a tuned filter connected between said supply means and the one of said inputs to which said one quantity is supplied, said filter including a Q controlling element, and Q controlling means operatively connected to said Q controlling element, said Q controlling means normally being effective to maintain a reduced Q in said filter so that a reduced storage of energy is maintained therein and the filter has a low time interval of response to a change in the phase of said one quantity, said Q controlling means being actuatable in response to a fault condition of said transmission line to raise the Q of said filter to increase its filtering ability.

2. The combination of claim 1 in which said one quantity is representative of current flow in said line and the other of said quantities is representative of a voltage condition of said line.

3. The combination of claim 2 in which said transmission line is polyphase and said Q controlling means is responsive to the presence of negative sequence current in said polyphase line.

4. The combination of claim 3 in which a second filter, tuned to the frequency of said transmission line, is connected to the input of said Q controlling means to reduce the effect of transient quantities.

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