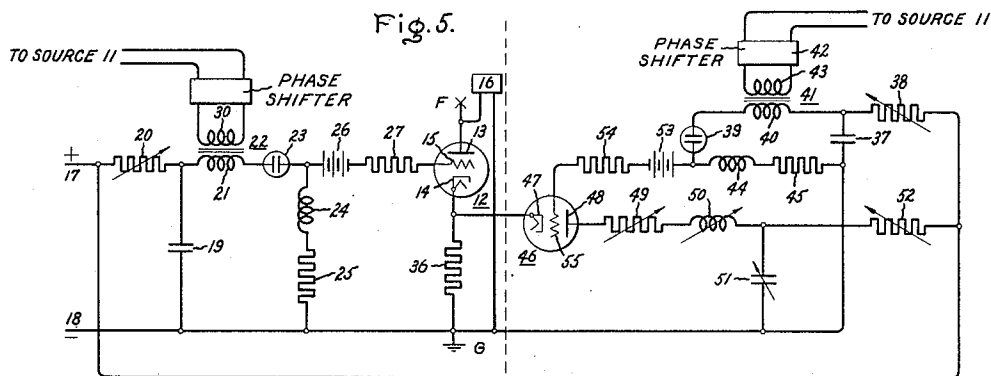
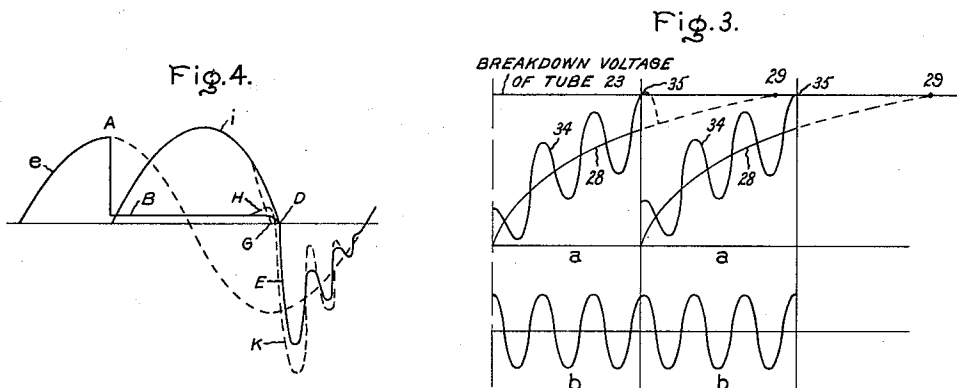
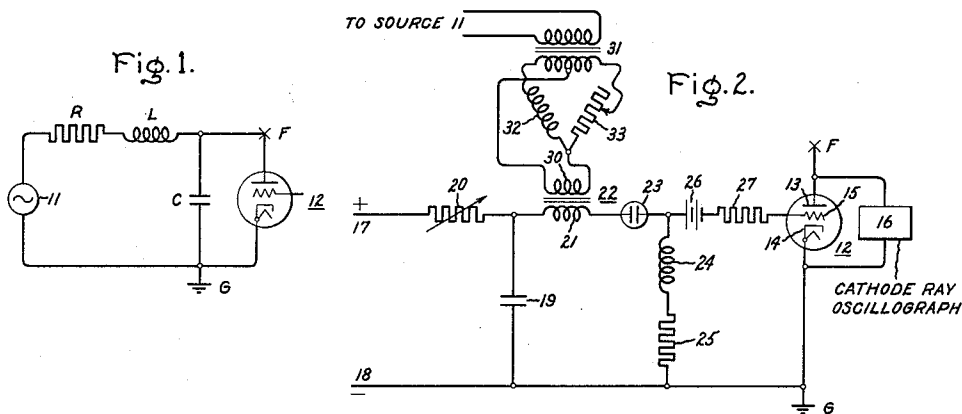


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TESTING OF ELECTRICAL CIRCUITS

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TESTING OF ELECTRICAL CIRCUITS

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This invention relates to electrical apparatus for investigating the transient fault and recovery voltage characteristics of electrical power circuits and more particularly to electrical apparatus including electric valves for recurrently applying and removing artificial faults to electrical circuits at predetermined time intervals in order to observe the characteristics of such circuits under various transient conditions.

My invention has for its principal object the provision of improved apparatus for investigating the transient recovery voltage characteristics of electrical power systems.

Another object of my invention is to provide improved apparatus for use with a miniature reproduction of a power system for producing phenomena similar to those which take place upon the interruption of an alternating current in the actual power system both at normal current zero and at points other than normal current zero.

Another object of my invention is the provision of improved apparatus for testing electrical circuits including electron discharge devices for recurrently applying and removing artificial faults to an alternating current circuit under test in synchronism with the voltage wave of the source of supply.

A further object of my invention is to provide improved apparatus for simulating transient conditions on a power system incident to the clearing of faults by expulsion tubes or circuit breaker apparatus, said improved apparatus including an electron discharge device for recurrently applying an artificial fault to the system and interrupting the fault current at or near the normal current zero of the alternating current wave and means to indicate the transient recovery voltage of the interrupted circuit in a simple manner.

A still further object of my invention is to provide improved apparatus for studying the effects on the recovery voltage characteristic of an electrical circuit of applying an artificial fault at different points on the voltage wave and interrupting the current at or near the first normal current zero after the application of the fault.

It is also an object of my invention to provide means for use in connection with my improved apparatus for controlling the magnitude and shape of the arc voltage characteristic for simulating the action of numerous fault clearing devices in electrical circuits under conditions of current interruption at other than normal current zero.

My invention will be better understood from the following description taken in connection with the accompanying drawing and its scope will be pointed out in the appended claims.

The successful application of certain protective devices, such as expulsion tubes and high voltage circuit breaker apparatus, as protective fault clearing or circuit interrupting devices on power systems requires an understanding of the transient electrical characteristics of the electrical circuit in which the devices are to be installed. It is a familiar fact that in the case of alternating current circuit breakers and expulsion tubes the current interruption through such devices takes place at or near the instant when the current wave passes through zero, and it is known that the operation or performance of such interrupting devices is very much influenced by the rate at which the transient recovery or restriking voltage of the circuit rises across the breaker or tube terminals immediately following the interruption of current flow. The successful clearing of a fault on the circuit or interruption of the current in the circuit depends upon the ability of the interrupting device to prevent the reestablishment of the arc after the current wave passes through zero and the arc is extinguished. It is, therefore, dependent upon the outcome of a race between the dielectric recovery voltage strength of the current interrupting device itself, and the transient recovery voltage of the electrical circuit in which the device is to operate, for if at any instant after interruption the dielectric recovery voltage of the interrupting device is less than the circuit recovery voltage, a restriking of the arc will occur. It thus becomes important to know not only the maximum value of this recovery voltage but also the rate at which it rises immediately following the interruption of current. This is substantiated by the fact that some interrupting devices have been seen to fail at less than their normal crest voltage rating.

It has therefore become desirable to provide improved apparatus for applying and removing artificial faults in synchronism with the voltage wave which may be used on an actual system or which may be used with a miniature equivalent circuit simulating the actual power system for determining the recovery voltage characteristic of the system for a period of time immediately following the interruption of current flow. With such apparatus one is enabled to study the effect on the transient recovery voltage characteristic of various fault conditions such as the

application of the fault at various points on the voltage wave, the interruption of the fault at or near normal current zero subsequent to fault application, as well as the effect of varying the character of the fault, such as, line-to-ground, line-to-line, double-line-to-ground, and the like. Also the location of the fault along the line with respect to the generating end, the length of the line, the arc voltage characteristic, the fault current, and the system voltage are important considerations which may likewise be taken into account.

Various methods have been employed for determining the recovery voltage characteristics of electrical circuits under fault conditions such as by analytical methods, by current injection and also by the use of mechanical interrupting devices, but for one reason or another these methods have not proved wholly satisfactory. Due to the number of cases to be considered, the range of conditions, and the rather involved nature of the problem in general, analytical methods have been found to be rather laborious and to have limited value. One also encounters serious limitations in the case where the circuit is opened by mechanical devices. The arc voltage characteristic of such devices is not controllable so that the difficulty of duplicating this characteristic is present at the outset. Time control is important in the application of the recurrent surge technique but with mechanical devices the timing is not accurate enough for use in investigations involving other than the lower frequency recovery voltages, because of the difficulty in getting a mechanical switch to apply the fault each time at the same point on the voltage cycle and to interrupt repeatedly at normal current zero, or at a predetermined point with respect thereto. Such mechanical devices also require careful adjustment. The parts are subjected to wear due to mechanical friction and arcing of the contacts when these mechanical devices are not adjusted to open the circuit at the normal current zero which necessitates frequent readjustments.

In carrying out my invention, I have provided improved apparatus with no moving parts for investigating the transient recovery voltages of an electrical circuit incident to the clearing of faults by expulsion tubes or the interruption of the circuit by circuit breaker apparatus. I employ a unilaterally-conductive electron discharge device to replace the actual expulsion tube or circuit breaker apparatus by means of which artificial faults may be recurrently applied to and removed from the circuit to be investigated in adjustable definite timed relation with the voltage of the circuit. The recovery voltage of the circuit which appears across the electron discharge device upon interruption of the circuit due to the cessation of current flow in the discharge device is then indicated directly by appropriate means such as a cathode ray oscillograph. In connection with such electron discharge device I provide means for varying the point on the voltage wave at which the fault is applied and also for varying the point with respect to normal current zero at which the fault is removed. I may also apply and remove the artificial fault at intervals of any desired number of cycles of the fundamental frequency, the maximum frequency of repetition in any case being dictated largely by the natural frequency and losses of the system under investigation while the minimum frequency of repetition must be such that due to the per-

sistence of vision an image will appear on the viewing screen of the oscillograph.

In accordance with a modification of my invention I provide means for simulating conditions of actual current interruption at other than normal current zero, for various types of current interrupting devices by providing means to control the magnitude and shape of the arc voltage characteristic as well as its application in proper time relation to the point of current interruption in order that all of the conditions which are most likely to exist in actual operation may be studied.

Referring to the drawing, Fig. 1 represents a power system or miniature equivalent circuit of a power system to be investigated together with an electron discharge device for applying a fault to the system. Fig. 2 is a diagrammatic representation of one embodiment of my invention wherein an electron discharge device with control therefor controls directly the recurrent application and removal of the fault to an electrical system to be investigated. Figs. 3 and 4 are graphs representing certain operating characteristics of the arrangement of Figs. 1, 2 and 5 to aid in the understanding of my invention, and Fig. 5 is a diagrammatic representation of a modification of my invention wherein the conditions of current interruption at other than normal current zero may be simulated.

In Fig. 1 I have shown a power system or miniature equivalent reproduction of the same to be investigated. The numeral 11 designates an alternating current source for supplying power to the circuit to be investigated, and R, L and C represent the circuit constants of the system including connected apparatus. The alternating current source of supply 11 for energizing the miniature system should be of sufficient capacity so that the voltage at its terminals remains essentially constant regardless of transient disturbances imposed in the circuits. This makes it possible to energize auxiliary equipment from the same source, thereby providing the necessary means for synchronization of fault application and removal. The point F designates any place in the network at which the recovery voltage following clearing of a fault or circuit interruption at that point is desired. This fault is shown occurring to ground; however my invention is not limited in its application to the simulation of such fault conditions but may be employed in any case wherein a fault occurs between any two points in a network, for example, line-to-line in a 3 phase system, or a double-line-to-ground fault. The artificial fault is applied and removed by means of an electron discharge device 12.

In Fig. 2 I have shown a diagrammatic sketch of the circuit employed for controlling the operation of the electron discharge device 12 for the purpose of recurrently applying and removing an artificial fault to the system of Fig. 1 at point F at definite intervals in synchronism with the voltage wave produced by the alternating current source 11. The electron discharge device 12 is provided with an anode 13, a cathode 14, and a control element 15, and may be of any of the several types well known in the art, although I prefer to use a valve of the mercury vapor grid controlled rectifier type having the characteristic that the initiation of current flow through the valve is controlled by the potential on the control element but after the flow of current once starts the control element is ineffective to limit or stop it and the current can be interrupted only after the anode potential has been reduced below its

critical value, after which the control element can regain control. When the discharge device 12 becomes conductive this results essentially in a short circuit between the points F and G as indicated, and in the miniature equivalent would represent a fault on the actual system.

It is a characteristic of expulsion tubes that they pass only a pulse of current lasting from the time of initiation of the fault until the first subsequent current zero. The arc voltage of such a tube is fairly constant throughout the interval of time during which the current is flowing, although there is a tendency for it to increase to a higher value just preceding interruption. In carrying my invention into effect, I take advantage of the fact that an electron discharge device of the mercury vapor grid controlled rectified type, for example, has an arc characteristic of its own which is very similar to the above mentioned characteristic of an expulsion tube in that it is practically constant during the entire time of current flow. It is also a familiar fact as already explained that the initiation of current flow through the discharge device is controlled by the potential on the grid, but the current can be interrupted only by reducing the anode potential below its critical value. By impressing a positive impulse voltage on the control element 15, which is properly timed with the source voltage 11 a fault may be applied to the system at any point on the voltage wave, and fault current will flow from the time the fault is applied until the first normal current zero when it is automatically interrupted by the discharge device 12. The voltage appearing across anode 13 and cathode 14 of the discharge device will correspond to the actual recovery voltage of the system, which voltage may be observed directly on the screen of a cathode ray oscillograph 16.

The arrangement shown in Fig. 2 provides means for timing the application and removal of the fault with the voltage of the source of supply 11 so that the transient repeats itself in synchronism with the steady state voltage wave. For producing an impulse on the control element 15 I provide a direct current source of supply 17, 18 for charging a condenser 19 through a resistance 20. The time constant of this series circuit 19, 20 may be varied to correspond roughly to the time for one, two or any arbitrarily selected number of cycles of base frequency. The discharge circuit for the condenser 19 includes the secondary winding 21 of a transformer 22, a gaseous discharge tube 23, such as a neon tube, for example, an inductance 24, and a resistance 25. The function of the transformer 22 is to inject an alternating voltage into the discharge circuit for accurately defining the point on the voltage wave at which the fault is to be applied and will be described more fully hereinafter. With the transformer 22 unexcited, when the voltage across the condenser 19 reaches the breakdown value of the discharge device 23 the condenser discharges rapidly through the inductance 24 and resistance 25, the time constant of this path being small as compared with 19, 20. The discharge will continue until the voltage across the condenser is insufficient to maintain ignition of the discharge tube 23. The purpose of the inductance 24 is to prolong the duration of this discharge so that the discharge device 12 will have ample time to ionize. Immediately after the tube 23 becomes non-conducting the condenser 19 begins to charge again and the cycle is repeated automatically. The discharge of the condenser pro-

duces a positive impulse of voltage across inductance 24 and resistance 25 which is impressed between the cathode 14 and the control element 15 in opposition to the negative biasing potential supplied by the voltage source 26 through the current limiting resistance 27. The discharge device 12 becomes conductive, applying a fault to the system at F, and the fault current will flow until the first normal current zero following fault application, at which time the current is interrupted and the negatively-biased control element 15 is allowed to regain control over the conductivity of the discharge device which it maintains until the next positive impulse of voltage is received due to the discharge of condenser 19.

A better understanding of my invention may be had by reference to the characteristic curves illustrated in Fig. 3. In Fig. 3a the voltage across the condenser 19 during the charging period is shown by the curve 28. With the transformer 22 unexcited the condenser voltage represented by the curve 28 appears across the arc discharge device 23 and with no other voltage in this circuit the discharge device 23 would break down at the point 29. However, in order to interlock the firing of the tube 23 with the reference frequency of the source of supply 11, I employ the transformer 22 to inject an alternating voltage into the discharge circuit of the condenser 19. The primary winding 30 of the transformer 22 is energized from the alternating current source 11 through any suitable phase shifting arrangement, such, for example, as an impedance phase-shifting circuit comprising a transformer 31 a reactor 32 and a variable resistor 33 connected in a well known manner. The transformer 22 therefore adds the alternating component of the base or reference voltage as shown in Fig. 3b to the condenser voltage 28. The resultant voltage appearing across the tube 23 is then of the form shown in Fig. 3a and designated by the numeral 34. The discharge device 23 will now break down at the point 35 instead of point 29. If the time constant of the condenser 19 and resistor 20 is made to correspond, for example, to 3 cycles of base frequency as indicated in Fig. 3a, the frequency of firing of the tube 23 is thus made to interlock with the reference frequency repeating as shown every 3 cycles. By variation of the constants 19, 20 the circuit can be adjusted to apply the fault at intervals of from 1 to several cycles, the allowable frequency of repetition of the fault depending upon the amount of damping in the circuit under investigation. Once the frequency of fault application has been selected, the phase shifter connected to transformer 22 can be adjusted so that the entire circuit can be made to select accurately the point on the voltage wave of the source of supply 11 at which it is desired to apply a fault. Thus with the system voltage of source 11 connected as in Fig. 1 the effect on the transient recovery characteristic between points F and G due to variation in the point on the voltage wave at which the fault is applied may be readily investigated, since the electron discharge device 12 will interrupt the fault current automatically at the first normal current zero subsequent to fault application regardless of the position on the voltage wave at which the fault occurred. As a further refinement the transformer 22 may be of the "peaking" type, that is, itself producing a sudden impulse every one-half cycle in place of reproducing a purely sinusoidal wave form as shown in Fig. 3b.

To summarize the method of operation, consider the circuit of the source of supply 17, 18 in Fig. 2 in the deenergized condition with no charge on the condenser 19, with the system voltage at point F applied between anode 13 and cathode 14 of the control discharge device 12, and with the phase shifter connected to the source of supply 11. Upon closing the circuit 17, 18 the condenser 19 begins to charge through the resistance 20 and the voltage of the condenser is added to the alternating voltage in the secondary winding 21. The tube 23 breaks down at point 35 and the condenser 19 suddenly discharges through inductance 24 and resistance 25 thereby impressing a positive impulse of voltage on the control element 15 and causing the discharge device 12 to become conductive and thereby applying a fault at point A on the voltage wave as shown in Fig. 4. As described previously, by adjusting the phase shifter I may apply the fault at any point along the voltage wave "e" of the source of supply 11 as desired.

Referring further to Fig. 4 for a better understanding of my invention, when the discharge device 12 becomes conductive at point A, the voltage drops to a value B which represents the arc voltage of the fault. At the instant the discharge device 12 becomes conductive, fault current begins to flow and forms a current loop "i" which is interrupted at the point D. Upon interruption of the fault current the transient recovery voltage characteristic of the circuit as indicated at E appears at point F on the system and between the anode and cathode of the electron discharge device 12. This voltage is impressed on a cathode ray oscillograph 16, as indicated in Fig. 2. The transient recovery voltage characteristic E of Fig. 4 is illustrated as having a time duration of approximately one quarter cycle of the fundamental voltage wave.

Inasmuch as the fault condition may be repeated at definite and controllable intervals in synchronism with the system base frequency, the repeated transient may be made to appear as a stationary image on the screen of oscillograph 16 for direct observation by means well understood in the art and if desired a photographic record of the phenomena may be obtained by taking short time exposures of the trace appearing on the fluorescent screen.

It has been observed in connection with the use of expulsion tubes that there is a tendency of such tubes in some cases to interrupt shortly before normal current zero. The arrangement shown in Fig. 5 represents a refinement over the apparatus of Fig. 2 which permits simulation of conditions of current interruption at other than normal current zero. The portion of the circuit to the left of the dotted line in Fig. 5 is identical to that already described and illustrated in Fig. 2. By means including a resistance 36 which is connected in series with the fault and in the cathode circuit of the electron discharge device 12 I may apply an artificial arc voltage of desired magnitude and shape to simulate conditions of interruption with various devices at other than normal current zero as well as at normal current zero. If this resistor is small relative to the impedance of the system viewed from the fault point its presence will be negligible as far as the fault current flow itself is concerned and will not appreciably alter the transient phenomena occurring in the miniature system. The effect on the fault current will be to increase the damping of higher frequencies slightly and shift the phase

angle of fault current very slightly. It has no effect on the recovery voltage itself since it is out of the circuit as soon as the fault current is interrupted. The purpose of that portion of the circuit to the right of the dotted line is to send recurring surges of current through the resistance 36 in proper definite timed relation with the application and removal of the fault such that interruption of fault current occurs sooner than it would if normal conditions were permitted to continue. As indicated in Fig. 4 the rate of current decay is increased and the circuit is interrupted at point G before the normal current zero. This is brought about by lowering the cathode-anode potential of the discharge device 12 at the proper instant and also by driving the control electrode 15 more negative at the same instant.

The method of timing the recurrent surges of current applied to the resistance 36 is essentially the same as that described in connection with Fig. 2. The condenser 37 is charged through resistance 38 and the value of this resistance and capacitance determines the frequency of repetition of the cycle of events in this surge circuit. As described in connection with the circuit in Fig. 2 the voltage appearing across the arc discharge device 39 is the sum of an exponentially rising component due to the charge on condenser 37 and an A. C. component injected into the discharge circuit of the condenser by means of the secondary winding 40 of transformer 41 which can be varied in phase position by means of the phase shifter 42 connected to the primary winding 43. When the condenser 37 discharges a voltage impulse appears across inductance 44 and resistance 45 in a manner similar to that which takes place in the apparatus of Fig. 2.

I employ an electron discharge device 46 which may be of the same type as the discharge device 12, and connect its principal electrodes, including a cathode 47 and anode 48, in circuit with a resistance 49, an inductance 50, a condenser 51 and the resistance 36. The condenser 51 is connected in circuit with a resistance 52 to the source of supply 17, 18 and is periodically charged thereby. The source of direct current 53 in circuit with a current limiting resistance 54 provides a negative biasing voltage on control element 55 to render the discharge device 46 normally nonconductive. When the charge on the condenser plus the alternating component of voltage in secondary winding 40 reaches a value sufficient to cause breakdown of the arc discharge tube 39, the condenser 37 discharges, thereby placing a positive impulse of voltage on the control element 55 and causing the discharge device 46 to become conductive. The condenser 51 then discharges through the circuit 49, 50, 51, 36 and 46 in a manner determined by these circuit constants. These constants will not only determine the magnitude of the surge of current passing through the resistance 36 but also its value as a function of time. The current impulse through the resistance 36 lowers the potential between the cathode and anode of the discharge device 12 and also tends to drive its control element 15 more negative with respect to the cathode 14, thereby causing an increase in the rate of current decay which produces an interruption of fault current before normal current zero as indicated at point G in Fig. 4. The curved portion H of Fig. 4 indicates the arc voltage characteristic of the fault clearing device and the dotted curve K represents the transient recovery voltage characteristic of the

circuit under investigation for interruption of fault current before normal current zero.

If desired a saturable reactor may be used in place of the inductance 50 to facilitate simulation of certain conditions wherein the arc voltage during the period just preceding interruption increases at a rate faster than the first power of time. Thus I am able to control both the magnitude and shape of the arc voltage characteristic just prior to current interruption which becomes very important in some cases. It should be understood that the condenser 51 begins to charge through resistance 52 immediately after each interruption of the fault current. Since a separate phase shifter 42 is employed for accurately timing the recurrent application of this voltage surge for simulating the arc voltage characteristic, the time of its application relative to fault current interruption may also be varied. The entire circuit therefore affords excellent flexibility in simulating the action of numerous fault clearing devices when used either with an actual power system or with an equivalent circuit which is a miniature reproduction of an actual power system.

The method of operation of the circuit portion at the left of the dotted line is identical to that of Fig. 2 and needs no further explanation. As for the operation of the remainder of the circuit shown in Fig. 5 it is only necessary that the constants of the circuit involving condenser 37 and resistance 38 should be so chosen that a recurrent current impulse is sent through inductance 44 and resistance 45 in properly timed relation to each fault application and removal. By means of the phase shifter circuit 42 the discharge of condenser 37 may be synchronously keyed with the source of supply 11 and a surge current may be sent through resistance 36 at selected points on the current loop "i". The magnitude and variation of this surge current with respect to time may be selected as desired by adjusting the constants in circuit with the principal electrodes of electron discharge device 46 including the condenser 51.

While I have shown the improved apparatus of my invention used for applying a line-to-ground fault on an electrical system, it may be used for applying a fault between any two conductors of a network as well. Furthermore, I may apply double-line-to-ground faults if desired by using two electron discharge devices and connecting their control elements in such a manner that both receive the same voltage impulse which appears across inductance 24 and resistance 25 so that the faults are applied to both lines at the same instant. It is also conceivable that several such devices may be used in combination to apply three-phase faults in a three phase system, or any combination of simultaneous faults or near simultaneous faults in any system. Obviously many variations of the time of application of a fault to the various phases as well as its removal are also possible as will readily occur to one skilled in the art.

As indicated previously the characteristics of the discharge device 12 are such that it may be used to advantage to simulate the arc voltage drop in such devices as expulsion tubes wherein the actual amount of arc drop is practically constant for all currents within its rating. The actual magnitude of the steady arc voltage B may be varied for specific cases by inserting a fixed direct current voltage in series with the discharge device 12 and the overall drop may thus

be made greater or smaller than the arc voltage of the discharge device 12 alone.

The embodiments of my invention illustrated and described herein have been selected for the purpose of clearly setting forth the principles involved. It will be apparent, however, that the invention is susceptible of being modified to meet different conditions encountered in its use, and I therefore aim to cover by the appended claims all the modifications within the true spirit and scope of my invention.

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

1. A device for investigating the transient characteristics of electrical power systems, comprising in combination, an electrical circuit to be tested including an alternating current supply source, an electron discharge device connected across said circuit, means for controlling the conductivity of said discharge device for applying an artificial fault to said circuit at a selected point on the voltage wave of said source and removing said artificial fault from said circuit, and means for observing the wave form of the voltage of said circuit.

2. Testing apparatus comprising an electrical circuit to be tested, a source of alternating current for energizing said current, an electron discharge device having its principal electrodes connected to said circuit, means for controlling the conductivity of said discharge device to apply an artificial fault to said circuit at a selected point on the voltage wave of said source and remove said artificial fault recurrently from said electrical circuit in synchronism with said alternating current source, and means for observing the transient recovery characteristic of said circuit.

3. In apparatus for testing the transient recovery characteristics of alternating current circuits, an electron discharge device having principal electrodes and a control element, means for connecting said principal electrodes across the circuit to be tested, an excitation circuit for said control element including an impedance device and means for biasing said control element to maintain said discharge device normally non-conductive, means for supplying a unidirectional current impulse to said impedance device to render said discharge device conductive at a selected point on the wave of the voltage supplying said circuit, and means for observing the wave form of the voltage across the circuit to be tested when said discharge device becomes nonconductive.

4. In apparatus for investigating the transient recovery characteristics of electrical circuits, an electrical circuit to be tested including an alternating current supply source, a unilaterally-conductive vapor electric discharge device having principal electrodes and a control element for controlling the conductivity between said principal electrodes, means for connecting the principal electrodes across the circuit to be tested, means for generating an impulse voltage having a predetermined adjustable phase and frequency relationship to the voltage of said source, means for applying to said control element a bias voltage and an impulse voltage from said impulse voltage generating means which is opposite in effect to said bias voltage and of sufficient magnitude to render said discharge device conductive, said bias voltage being of sufficient magnitude to enable said control element to regain control of said discharge device when the potential of said

principal electrodes is reduced below the critical value, and means for observing the transient recovery characteristics of the electrical circuit under test.

5. In a device for investigating the transient characteristics of electrical circuits, an electrical circuit to be tested including an alternating current supply source, a unilaterally-conductive vapor electric discharge device having principal electrodes and a control element for controlling the conductivity between said principal electrodes, said principal electrodes being connected across the circuit to be tested, means connected with said control element for rendering said discharge device nonconductive, means operative in predetermined adjustable phase and frequency relationship to the voltage of said supply source for rendering said first mentioned means ineffective, whereby said discharge device is allowed to become conductive for applying an artificial fault to said electrical circuit, and means for observing the wave form of the voltage of the circuit under test.

6. Testing apparatus comprising an electrical circuit to be tested, a source of alternating current for energizing said circuit, a unilaterally-conductive electron discharge device having its principal electrodes connected to said circuit, means for controlling the conductivity of said discharge device to apply an artificial fault to said circuit at a selected point on the voltage wave of said source, means for generating an impulse voltage of controllable time duration, means for injecting said impulse voltage in the circuit of said principal electrodes at a predetermined time prior to normal current zero in said discharge device, and means for observing the transient recovery characteristic of said electrical circuit.

7. In a device for investigating the transient recovery characteristics of an electrical circuit connected to an alternating current source of supply, a unilaterally-conductive electron discharge device having principal electrodes and a control element, means for connecting said principal electrodes across the circuit to be tested, means for biasing said control element to maintain said discharge device nonconductive, means for generating an impulse voltage of adjustable frequency and time phase with respect to the voltage of said source of supply, means for impressing said impulse voltage on said control element in opposition to said biasing means to cause said discharge device to become conductive for applying an artificial fault to said electrical circuit, means in circuit with said principal electrodes for causing the interruption of current flow in said discharge device prior to normal current zero, and means for observing the transient recovery voltage of said electrical circuit.

8. In a device for investigating the transient characteristics of electrical power systems, an electrical circuit to be tested including an alternating current supply source, a unilaterally-conductive vapor electric discharge device having its principal electrodes connected across said circuit, a control element for controlling the conductivity of said discharge device, means for applying a biasing potential to said control element to maintain said discharge device nonconductive, means

in circuit with said control element for rendering said first mentioned means ineffective, whereby said discharge device is made conductive for applying an artificial fault to said electrical circuit, means operable after said device becomes conductive and at a predetermined time prior to normal current zero for causing interruption of current flow in said discharge device prior to said normal current zero, and means for observing the wave form of the voltage which appears across the circuit under test.

9. In a device for investigating the transient recovery characteristics of an electrical circuit connected to an alternating current source of supply, a unilaterally-conductive electron discharge device having principal electrodes and a control element, means for connecting said principal electrodes across the circuit to be tested, means for applying a biasing voltage to said control element to maintain said discharge device nonconductive, means for generating an impulse voltage of adjustable frequency and time phase with respect to the voltage of said source of supply, means for impressing said impulse voltage on said control element in opposition to said biasing voltage to cause said discharge device to become conductive for applying an artificial fault to said electrical circuit, means for generating a second voltage impulse of adjustable frequency and time phase with respect to the voltage of said source of supply, means for injecting said second impulse voltage in the circuit of said principal electrodes at a predetermined time interval prior to normal current zero in said discharge device to cause the interruption of current flow in said discharge device prior to said normal current zero, and means for observing the wave form of the recovery voltage of said electrical circuit.

10. A device for investigating the transient characteristics of electrical power systems, comprising in combination, an electrical circuit to be tested including an alternating-current supply source, an electron discharge device connected across said circuit, means for controlling the conductivity of said discharge device for applying an artificial fault to said circuit at a selected point on the voltage wave of said source and removing said artificial fault from said circuit, said control means including means for varying the frequency of application and removal of said artificial fault, and means for observing the wave form of the voltage of said circuit.

11. Testing apparatus comprising an electrical circuit to be tested, a source of alternating current for energizing said circuit, a unilaterally-conductive electron discharge device having its principal electrodes connected to said circuit, means for controlling the conductivity of said discharge device to apply an artificial fault to said circuit at a selected point on the voltage wave of said source, means including an impedance element for injecting a controllable impulse voltage into the circuit of said principal electrodes, said impedance element being connected in circuit with said principal electrodes, and means for observing the transient recovery characteristic of said electrical circuit.

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