

Aug. 6, 1946.

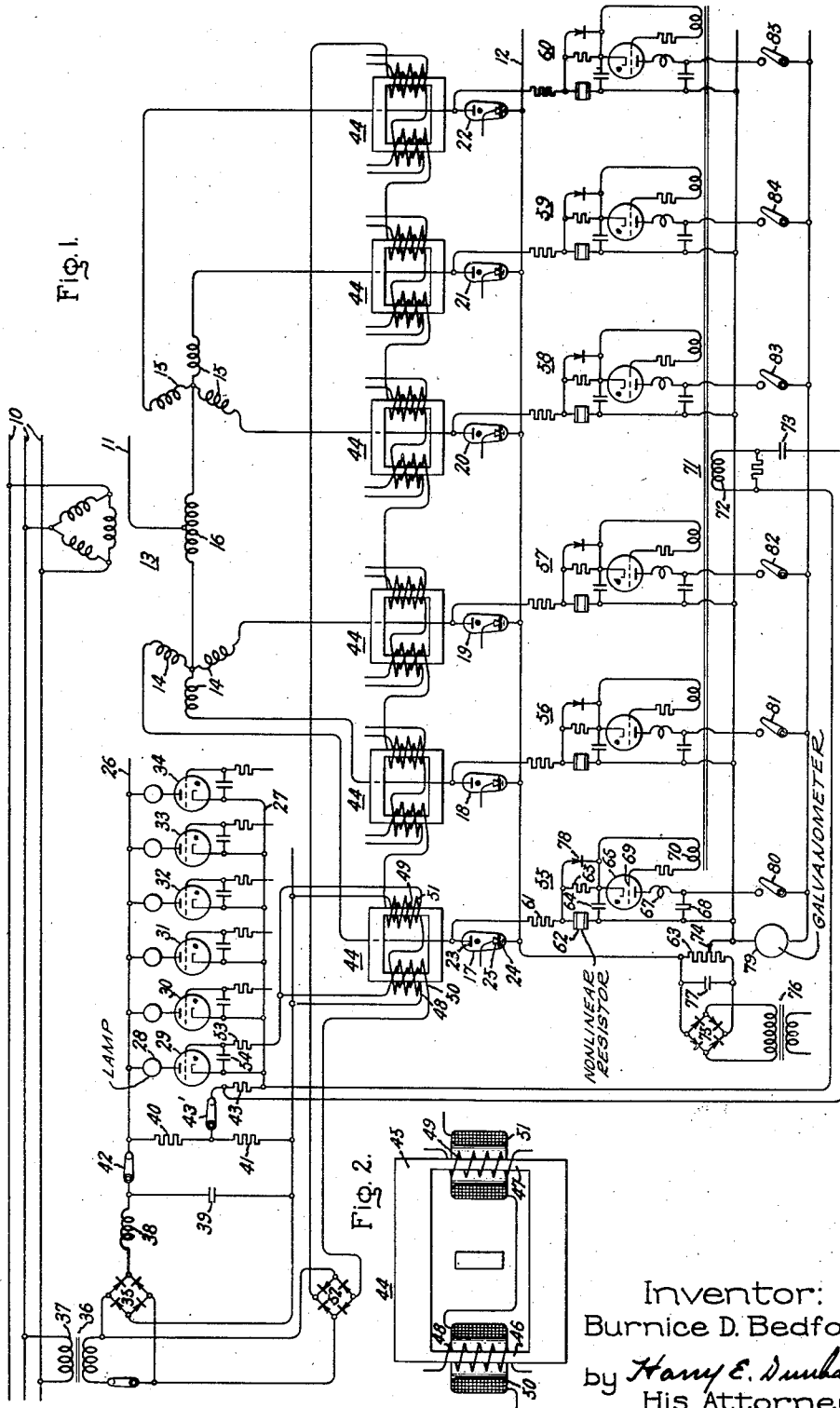
B. D. BEDFORD

2,405,397

ELECTRIC CIRCUIT

Filed Feb. 12, 1943

3 Sheets-Sheet 1



Inventor:
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Aug. 6, 1946.

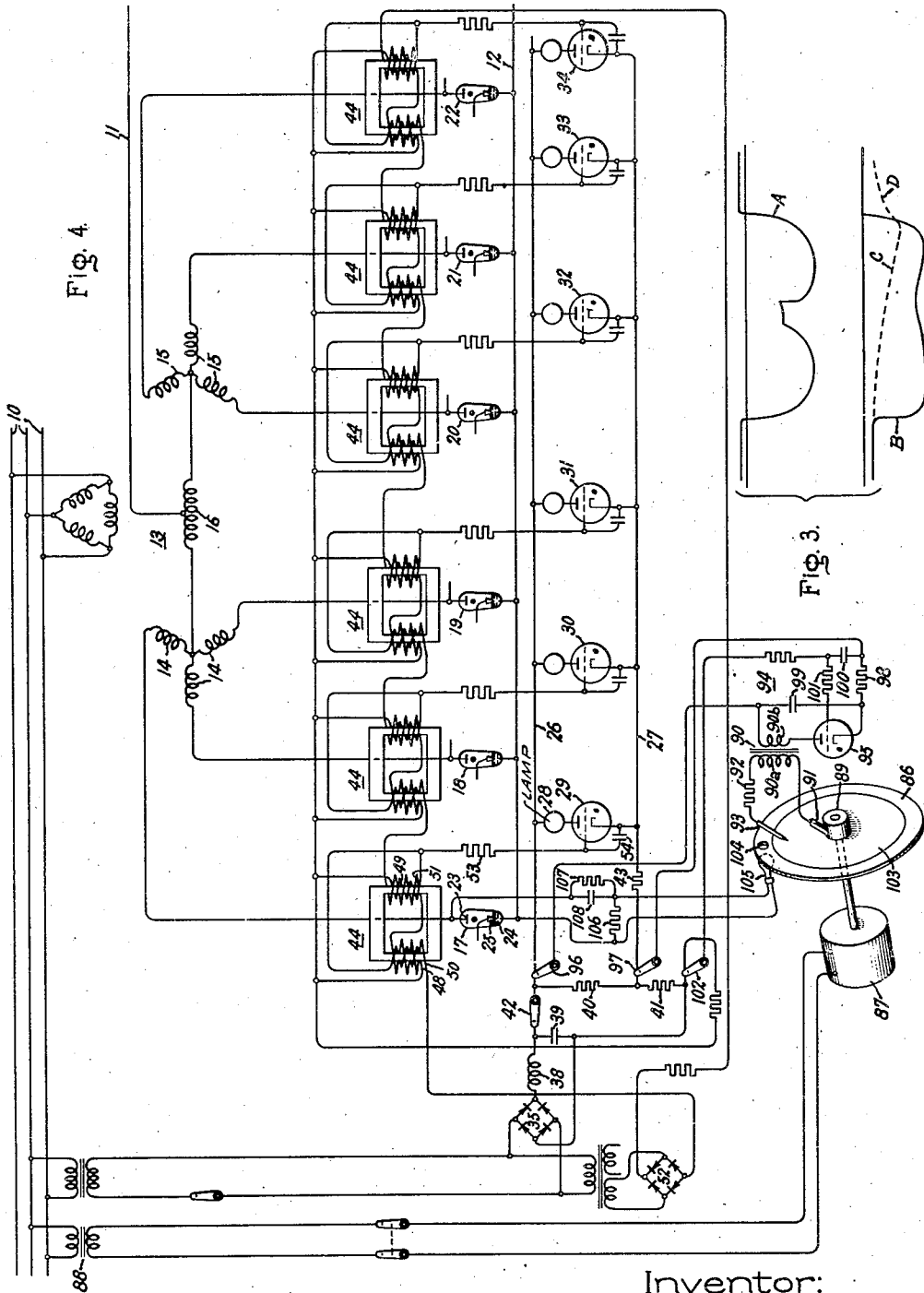
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ELECTRIC CIRCUIT

Filed Feb. 12, 1943

3 Sheets-Sheet 2



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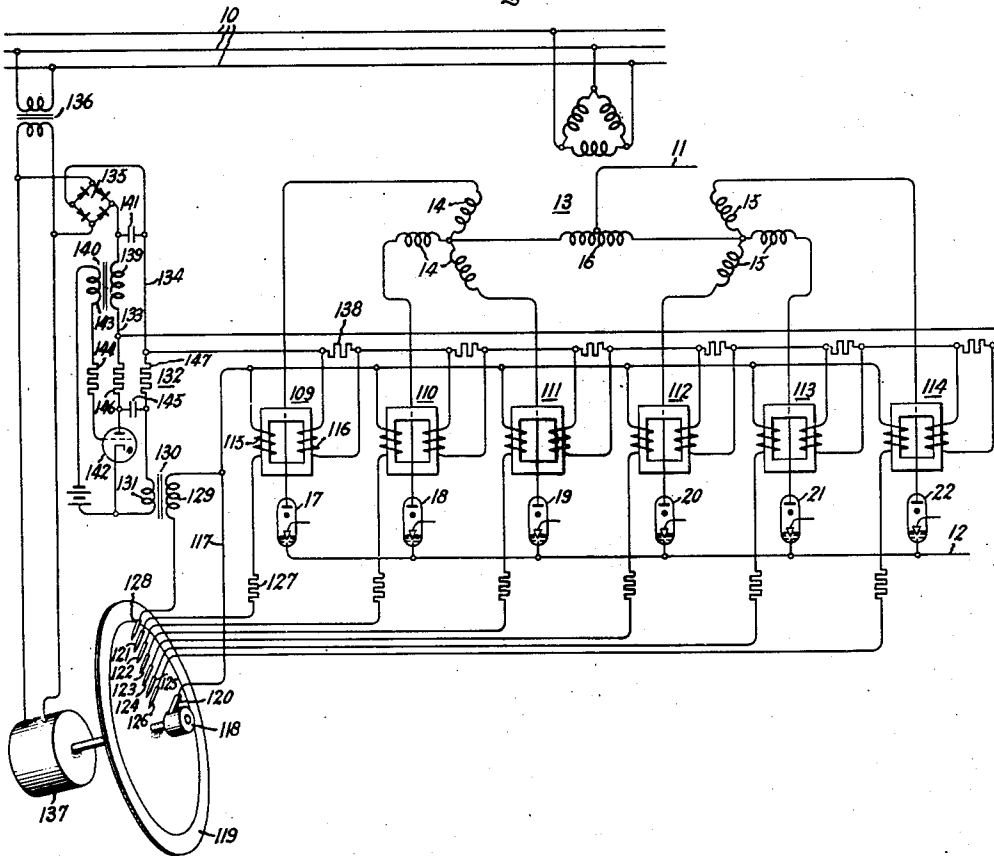
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ELECTRIC CIRCUIT

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3 Sheets-Sheet 3

Fig. 5.



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UNITED STATES PATENT OFFICE

2,405,397

ELECTRIC CIRCUITS

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New York

Application February 12, 1943, Serial No. 475,645

13 Claims. (Cl. 234—1.5)

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My invention relates to electric control and indicating circuits particularly adapted for use in connection with electric valve means for indicating abnormal operation thereof.

Electrical apparatus employing electric valves of the type utilizing an ionizable medium has been extensively used in industrial applications. These electric valves, which normally conduct in one direction only, sometimes conduct in the reverse direction. The reverse current is usually many times larger than the normal forward current and has caused considerable operating difficulty in systems of this type. From the standpoint of the operator, it is desirable to know which valve arcs back first in order that it may be removed from the system and reconditioned in the event that it fails persistently. From the standpoint of design, it is desirable to know in addition the time in the anode-cathode voltage wave that the arc-back occurs since this information is of assistance in determining the cause of the arc-back and the features of design which may be modified to eliminate the fault. In accordance with the teachings of my invention, I provide new and improved electric circuits for indicating which one of a number of transients, such as those caused by arc-back of an electric valve means occurs first and further for indicating the time in the cycle of the anode-cathode voltage of the valve means at which the arc-back occurs.

It is an object of my invention to provide a new and improved electric circuit for indicating the first of a plurality of transient conditions.

It is another object of my invention to provide a new and improved electric indicating circuit for indicating the instant in the anode-cathode voltage wave that an electric valve conducts in the reverse direction.

It is another object of my invention to provide an improved electric circuit for indicating the first of a plurality of electric valves to conduct in a reverse direction and to record the time in the anode-cathode voltage of the valve that reverse conduction is initiated.

In accordance with the illustrated embodiments of my invention, an improved electromagnetic device is associated with each of the anode conductors of an electric valve system to produce an impulse of voltage upon the occurrence of an arc-back in the associated electric valve. An indicating circuit having a controlled electric valve and an indicating device in series for each electric valve of the power system is provided

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and each of the controlled electric valves is energized in accordance with the voltage produced by the electromagnetic device associated with a corresponding one of the main electric valves.

When any one of the controlled valves conducts in response to an arc-back in the corresponding main valve, the remainder of the controlled electric valves are prevented from operating. An auxiliary circuit associated with each of the main electric valves and controlled in response to conduction of any one of the controlled electric valves of the indicator circuit provides means for indicating the time in the anode-cathode voltage wave at which the arc-back occurs. In accordance with another illustrated embodiment of my invention, the time in the anode-cathode voltage wave at which the arc-back occurs is recorded on a synchronously rotated disk by means of a sparking electrode energized by a voltage impulse at the instant of the arc-back.

My invention will be better understood by reference to the following description taken in connection with the accompanying drawings and its scope will be pointed out in the appended claims. In the drawings, Fig. 1 is a schematic representation of one embodiment of my invention, Fig. 2 is an enlarged view showing in detail one of the electromagnetic devices employed in the embodiment illustrated in Fig. 1, Fig. 3 represents certain operating characteristics of the circuit illustrated in Fig. 1, and Figs. 4 and 5 are schematic diagrams of other embodiments of my invention.

Referring now to Fig. 1 of the drawings, I have shown my invention embodied in an indicating circuit applied to an electric valve translating apparatus connected between a polyphase alternating-current circuit 10 and a direct-current circuit comprising conductors 11 and 12. In the following description it will be assumed that the electric valve apparatus is operating as a rectifier, in which case, the circuit 10 is the supply circuit and the conductors 11 and 12 constitute the load circuit. The translating apparatus includes a transformer 13 having groups of electrically displaced secondary windings 14 and 15 having neutral connections interconnected by an interphase transformer 16. The phase terminals of the windings 14 and 15 are connected with the direct-current conductor 12 through electric valves 17 to 22, inclusive. A midpoint on the interphase transformer 16 is connected with the other direct-current conductor 11. Each of the electric valves, as illustrated, comprises an anode 23, a cathode 24, and an immersion-ignitor con-

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trol member 25. In order to simplify the drawings, no energizing circuits for control member 25 have been illustrated and it will be understood that any of the types of control known in the art may be used, if desired.

I provide an indicating circuit including a plurality of parallel electric paths, the number of paths corresponding to the number of main electric valves in the rectifier system. The electric paths are energized in parallel across conductors 26 and 27 and each comprises an indicating device such as an electric lamp 28 and a controlled electric valve. The valves, as indicated by the dot within the envelope, are of the gaseous type and are designated by numerals 29 to 34, inclusive, and correspond respectively to the main electric valves 17 to 22, inclusive. The other valves of the various illustrated embodiments which are of the gaseous type are similarly indicated. As a means for energizing the conductors 26 and 27, I provide a full-wave rectifier 35 energized from a transformer 36 having the primary winding 37 thereof connected with the alternating-current supply circuit 10. The output of the rectifier 35 is filtered by a series reactor 38 and parallel capacitor 39 and impressed on voltage-dividing resistors 40 and 41 through a manual switch 42. The conductor 26 is connected with one terminal of the resistor 40 and the conductor 27 is connected with the common terminal of resistors 40 and 41 through a resistor 43 and a manual switch 43'.

In order to provide a source of control voltage for the electric valves 29 to 34 dependent upon an arc-back condition in the electric valves 17 to 22, respectively, I provide a plurality of electromagnetic devices illustrated generally by the numeral 44, and one of which is associated with the anode conductor of each of the electric valves. Referring briefly to Fig. 2, each of the electromagnetic devices comprises a closed magnetic circuit 45 including oppositely disposed legs 46 and 47 of smaller cross section than the connecting end portions of the core. Control windings 48 and 49 are wound on the legs 46 and 47, respectively, and direct-current saturating windings 50 and 51 are positioned on the legs 46 and 47 on the outside of the control windings 48 and 49. As illustrated in the drawings, the direct-current coils 50 and 51 of each device 44 are connected in series. Referring again to Fig. 1, it will be noted that the direct-current windings of the devices 44 associated with the anode conductors of all of the electric valves are connected in series and energized from a source of direct current which may be derived from the transformer winding 36 by means of a full-wave rectifier 52. The control windings 48 and 49 are connected in parallel and one common terminal thereof is connected to the control member of the corresponding electric valve 29 through a resistor 53. The other common terminal of the control winding is connected to the negative terminal of voltage-dividing resistor 41 which provides a source of negative bias for the electric valve 29 and, as previously mentioned, is connected to the cathode thereof through switch 43' and resistor 43. A capacitor 54 is connected between the control member and cathode of each of the electric valves 29 to 34. The control windings of the device 44 associated with main electric valve 17 are the only ones that have been shown connected in the drawings. It will be understood that the control windings of the remaining devices associated with valves 18 to 22 are

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similarly connected in the control-to-cathode circuit of electric valves 30 to 34.

Before describing the operation of the indicating circuit, the arrangement provided in Fig. 1 for indicating the time in the anode-cathode voltage cycle of each of the electric valves 17 to 22 at which an arc-back occurs will be described. Associated with the valves 17 to 22, inclusive, are the control circuits 55 to 60 respectively. These circuits are identical and the same reference numerals will be employed to designate the corresponding parts and only one will be described. Referring to the circuit 55, a linear resistance 61, a nonlinear resistance 62, and a portion of resistance 63 which provides a source of unidirectional voltage are connected in series across the anode-cathode circuit of the electric valve 17. The resistance elements 62 are preferably of the type having a negative-current impedance characteristic so that the voltage across the terminals thereof is maintained substantially constant. These resistance elements may be formed of a material disclosed and claimed in United States Patent 1,822,742, granted September 8, 1931, of Karl E. McEachron and assigned to the assignee of the present invention. The voltage appearing across the nonlinear resistance element 62 is utilized for charging a capacitance 64 through a resistance 65 in accordance with the inverse voltage of the electric valve 17. An electric valve 66, an inductive element 67, and a capacitance 68 are connected in series across the capacitor 64. The electric valve 66 is of the type employing an ionizable medium, as indicated by the dot within the envelope, and is provided with a control member 69 which is energized by a secondary winding 70 of the transformer 71 to render the electric valve conductive at the instant one of the main electric valves arcs back. This is accomplished by energizing the primary winding 72 of the transformer in accordance with the voltage appearing across resistor 43 which, as will be brought out in more detail at a later point in the specification, impresses a transient voltage on the winding 72 at the time that the first one of these electric valves 29 to 34 becomes conductive. A capacitor 73, connected in series with winding 72, prevents steady-state direct current from flowing in the primary winding 72. The voltage drop appearing across the upper portion of resistor 63 is adjusted by the slider 74 so as to be equal substantially to the normal arc drop of the electric valve 17 and the electric valve 66. The voltage for energizing the resistor 63 may be obtained in any suitable manner and is derived from the output of a rectifier bridge 75 energized from a transformer 76 which may, in turn, be energized from any suitable source of alternating current, such as the supply circuit 10. A capacitor 77 connected in parallel with resistor 63 provides a low-impedance path for transient voltages and permits the rapid discharge of the condenser 64 during conduction of the valve 17 through a path which includes the resistor 61 and the anode-cathode circuit of the valve 17. A unilaterally conducting device 78 is connected in parallel with resistor 65 and is poled to provide a second discharge path for capacitor 64 during the conducting period of the electric valve 17. As will become more apparent after a description of the operation of the system described above, the magnitude of the charge on the condenser 62 after an arc back will be an indication of the time in the anode-cathode voltage wave of the

associated main electric valve at which the arc-back occurred. In order to measure this voltage, I provide a measuring instrument, such as a galvanometer 79, which may be selectively connected in circuit with the capacitor 68 of circuits 55 to 60 by means of manual switches 89 to 85, respectively.

A better understanding of the features and advantages of my invention may be had by a brief consideration of the operation of the system as a whole. Let it be assumed that the electric valves 17 to 22 are operating normally as a double three-phase rectifier to supply uni-directional current to the conductors 11 and 12. The electromagnetic devices 44 associated with the anode leads of the electric valves 17 to 22 are saturated sufficiently as a result of the uni-directional current flowing in the windings 59 and 51 so that the decay of current through the associated electric valves during normal operation induces only a small voltage in the control windings 48 and 49. The negative biases impressed on the electric valves 29 to 34 by resistor 41 together with the time constant of the circuit including resistor 53 and capacitor 54 cooperate to maintain the valve nonconductive during this operation. If electric valve 17, for example, conducts current in a reverse direction, the change in flux in the core 45 will be many times that occasioned by the normal decay of current through the electric valve 17 when it becomes nonconducting. A relatively large impulse of voltage is induced in the windings 43 and 49 and this is impressed on the control member of electric valve 29 and the associated indicating lamp 28 is energized. From an inspection of the drawings, it will be noted that conduction of any one of the valves 29 to 34 will increase the negative bias impressed on the control members of the remaining valves by resistor 41 and resistor 43 and, assuming that resistor 43 is substantially smaller than resistor 49, will simultaneously decrease the anode-cathode voltage of these valves appearing between conductors 26 and 27. This increase in negative bias and decrease in anode-cathode voltage is sufficient to prevent more than one of the electric valves 29 to 34 from becoming conductive regardless of the number of main electric valves which arc back. Thus, only the first arc back to occur is indicated.

In the above discussion, it was pointed out that all of the direct-current windings are connected in series and the control windings are located on opposite legs of the device 44 and connected in parallel. This arrangement of windings has numerous advantages. With the control windings connected directly in parallel, there is established a low-impedance closed circuit including these two coils so that any tendency for there to be a change in flux in one leg without a corresponding change in flux in the same direction in the other leg is opposed by a circulating current in the low-impedance circuit which substantially prevents any quick change in flux in the two legs in opposite directions due to stray flux from other phases of the system. This arrangement of windings and the relatively large cross section of the core legs between the winding legs prevents false operation of the indicating system due to stray flux not symmetrically located with respect to the coils. The series connection of the direct-current windings provides considerable impedance in the direct-current circuit and minimizes the effect of transient voltages in this circuit.

When the electric valves 17 to 22 are operating normally, the capacitor 64 is periodically charged during the inverse-voltage cycle and discharged quickly at the end of this voltage cycle. The voltage across resistor 63 is employed to insure an initial charge on the capacitor 64 at the beginning of the inverse-voltage cycle corresponding to the break-down voltage of the electric valve 66. Referring particularly to Fig. 3, the inverse voltage of electric valve 17 is illustrated by curve A. Curve B illustrates the voltage across the nonlinear resistance 62 with the initial negative voltage being determined by the setting of the slider 74 on resistor 63. The dotted curve C illustrates the voltage of the capacitor 64, which may be operated over such a range that the increase in voltage is substantially linear. At the end of the inverse-voltage cycle, the voltage on the condenser is rapidly discharged as illustrated at D through the unilaterally conducting device 78. In the event that an arc-back occurs in electric valve 17 at any time during the inverse-voltage cycle, the electric valve 29 is rendered conductive and a transient voltage appears across resistor 43. This voltage through transformer 71 renders each of the electric valves 66 of circuits 55 to 60, inclusive, conductive and the charges on capacitors 64 are transferred to the corresponding capacitors 68 through the anode-cathode circuits of the associated valves 66. The inductance 67 renders the discharge circuit of capacitor 64 oscillatory to insure reversal of the anode-cathode voltage of valve 66 and a termination of its conduction. The capacitor 68 having no discharge circuit established for it will hold its charge for a comparatively long period of time. The operator, upon observing from the lamps 28 that one of the electric valves has arced back may close one of the switch 89 to 85 corresponding to the first valve to arc back and read the deflection of the galvanometer 79 to determine the time during the inverse-voltage cycle that the arc-back occurred. It is apparent that calibration charts may be made for any given voltage of the system so that the deflection of the galvanometer may be converted to a phase position of the arc back. In order to reset the system for a subsequent operation, the control electric valves 29 to 34 may all be rendered nonconducting by opening switch 42 or 43' to remove the anode-cathode voltage and the capacitors 68 may be completely discharged by temporarily closing the manual switches 89 to 85, inclusive.

In Fig. 4, I have illustrated a modification of my invention in which a different arrangement for recording the time in the inverse-voltage cycle at which the arc-back occurred is provided. The system for indicating which one of the various phases arcs back first is the same as that described in connection with Fig. 1 and corresponding parts have been designated by the same reference numerals. In the arrangement shown in Fig. 4, the time in the inverse-voltage cycle at which the arc-back occurs is recorded on a disk by means of an electrical impulse which is produced when the arc-back occurs. This disk is rotated synchronously with the voltage of the supply circuit in the sense that the cycles of operation of the disk and the alternations of the voltage of the supply circuit bear a timed relation to each other. Referring now to Fig. 4, a rotating disk 86 is mounted on the shaft of a synchronous motor 87 which is energized from the alternating-current supply circuit 19 through

a transformer 88. The disk is preferably of good conducting material and is provided with a central hub 89 which is electrically connected with one terminal of the transformer winding 90a by means of a brush contact 91. The other terminal of the winding 90a is connected through a resistor 92 with a recording electrode 93 which is held in proximity to the rotating disk by any suitable means not shown. An impulse is produced in the winding 90a upon the occurrence of an arc-back in any one of the electric valves 17 to 22 by means of a circuit illustrated generally by the numeral 94. The circuit 94 includes an electric discharge device 95 which is connected in series with the primary winding 90b of the transformer 90 and across the voltage-dividing resistor 40 through manual switches 96 and 97. A resistor 98 is also connected in this circuit. An energy-storage capacitor 99 is connected across the electric valve 95 and the series connected transformer winding 90b to be charged from the resistor 40 through resistor 98. The control member of the electric valve 95 is connected with the cathode thereof through the resistor 98, a capacitor 100, and resistor 101. The common terminal of capacitor 100 and resistor 101 is connected through manual switch 102 with the negative terminal of resistor 41. With this arrangement, the control member of the electric valve is maintained at the potential of the negative terminal of resistor 41 when the electric valve system including valves 17 to 22 is operating normally. The capacitor 99 is charged to the full voltage appearing across resistor 40. As pointed out in connection with the operation of the arrangement of Fig. 1, the voltage across resistor 40 is reduced and the voltage across resistor 41 is increased at the instant any of the electric valves 29 to 34 are rendered conductive in response to an arc-back in a corresponding one of the main electric valves 17 to 22. This momentarily renders the control member of the valve 95 positive with respect to the cathode thereof and effects discharge of capacitor 99 through the transformer winding 90b and, as a result, causes a spark to jump from the electrode 93 to the disk 85 and, in this way, forms a hole in the paper chart 103 which is secured on the face of the disk 85 in any desired manner.

In order that the hole in the paper will indicate the time in the inverse-voltage cycle that the arc-back occurs, I provide means for synchronizing the disk 86 with the inverse-voltage cycle of the electric valves 17 to 22. As illustrated in the drawings, the disk is provided near the edge thereof with an opening 104 behind which is mounted a lamp 105, which may be supported in any suitable manner, and which is energized in accordance with the voltage across a resistor 106. The resistor 106 is connected in series with a parallel connected resistor 107 and capacitor 108 and across the anode-cathode circuit of the electric valve 17. The constants of the circuit including resistors 106 and 107 and the capacitor 108 are so chosen that the lamp is illuminated only during the rapid change of voltage across the electric valve 17 occurring at the beginning of the inverse-voltage cycle. In this way, the lamp is made to flash at the beginning of the inverse-voltage cycle and, by adjusting the disk on the shaft of the motor or adjusting the phase of the voltage impressed on the motor windings, a definite reference or zero position of the disk may be established. Inasmuch as the phase relation of the voltages of all of the electric valves is known with respect to the voltages of the valve

17, the instant of arc-back in the inverse-voltage cycle of any of the valves may readily be determined.

In Fig. 5, I have illustrated another embodiment of my invention in which the occurrence of an arc-back in any one of the main electric valves is recorded and in which means are provided for indicating which of the valves arcs back first. In Fig. 5, the power system is the same as that described and illustrated in Fig. 1 and the same reference numerals have been used to designate corresponding parts. In the arrangement shown in Fig. 5, the electromagnetic devices associated with the anode conductors of each of the electric valves may be the same as those described in connection with Fig. 1. However, as illustrated in Fig. 5, these devices, designated by the numerals 109 to 114, each includes only a single control winding 115 and a single saturating winding 116. One terminal of each of the control windings is connected to a common conductor 117 which is, in turn, connected with the hub 118 of a rotating disk 119 through a brush contact 120. The other terminals of the windings 115 are connected with recording electrodes 121 to 126, inclusive, through suitable current-limiting resistors 127. An additional electrode 128 is connected with the conductor 117 through the secondary winding 129 of a transformer 130, the primary winding 131 of which is energized only upon the occurrence of the first arc-back by a control circuit illustrated generally by the numeral 132.

The saturating winding 116 of the devices 109 to 114, inclusive, are connected in series and for energization from the conductors 133 and 134 which are energized by direct current from the output terminals of a rectifier bridge 135. The bridge 135 may be energized from the alternating-current supply circuit 10 through the transformer 136 which also provides a source of power for the motor 137 which drives the recording disk 119. Across the terminals of each of the saturating windings 116 is connected a resistance element 138 so that, upon the occurrence of an arc-back in any one of the main electric valves 17 to 22, the transient voltage produced across one of the resistors is impressed on the conductors 133 and 134 through a noninductive circuit. This impulse of voltage is impressed on the primary winding 139 of a transformer 140 through a capacitor 141 to render conductive an electric valve 142. The valve 142 has the control member thereof connected with the secondary winding 143 of the transformer winding 140 through a suitable current-limiting resistor 144 and the anode-cathode circuit thereof connected in series with the primary winding 131 of transformer 130 and a capacitor 145 which has been charged through resistors 146 and 147 from the direct-current supply conductors 133 and 134.

The operation of the embodiment of my invention illustrated in Fig. 5 may be briefly described as follows. When the electric valves 17 to 22 are operating normally, the voltages induced in the windings of devices 109 to 114, inclusive, are relatively small and no sparks are caused to jump from the recording electrodes to the rotating disk. Upon the occurrence of an arc-back, a voltage impulse of large magnitude is induced in the winding 115 of the electromagnetic device associated with the valve which has failed and a spark is caused to pass from the corresponding electrode to the rotating disk 119. At the same instant, the voltage impulse induced in the saturating winding 116 is impressed on the trans-

former winding 139 and renders electric valve 142 conductive to discharge condenser 145 through the transformer 130 and thereby to cause a spark to jump from the electrode 128 to the revolving disk 119. Inasmuch as all of the recording electrodes are supported in alignment on a radius of the disk 119, there will be two holes in the record paper upon the occurrence of the first arc-back and only one hole for each arc-back occurring thereafter, if the disk 119 is rotated at a relatively slow speed, it may be possible to record all the arc-backs occurring in one sequence before the chart makes a complete revolution. It will be readily appreciated that the arrangement shown in Fig. 5 may be operated to indicate or record the time in the inverse voltage cycle at which the arc-back occurs by synchronizing the position of the disk 119 with the inverse voltage cycle of one of the main electric valve means 17 to 22 in the same manner as described in detail in connection with Fig. 4.

Although resistors 132 have been shown connected across windings 116, it will be obvious to those skilled in the art that rectifiers suitably poled may replace such resistors without departing from my invention.

While I have shown and described particular embodiments of my invention, it will be obvious to those skilled in the art that changes and modifications may be made without departing from my invention in its broader aspects, and I, therefore, aim in the appended claims to cover all such changes and modifications as fall 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. In combination, an electric valve means, means for rendering said electric valve means conducting and nonconducting during predetermined intervals and for subjecting said valve means to an inverse voltage cycle during each of the normally nonconducting intervals, said electric valve means being subject to an arc-back during said inverse voltage cycle, an energy storage device, means for supplying electric energy to said energy storage device, means including an electric discharge device connected to be rendered conductive in response to the occurrence of an arc-back in said electric valve means for releasing the energy of said energy storage device, and means connected to be energized in accordance with the release of energy of said energy storage device for determining the instant in the inverse voltage cycle that an arc-back in said electric valve means occurs.

2. In combination, an electric valve means, means for rendering said electric valve means conducting and nonconducting during predetermined intervals and for subjecting said valve means to an inverse voltage cycle during each of the normally nonconducting intervals, said electric valve means being subject to an arc-back during said inverse voltage cycle, means including an energy storage device for producing an electric quantity which varies progressively in accordance with the duration of the inverse voltage cycle, means responsive to the magnitude of said electric quantity at the instant of an arc-back for indicating the time in the inverse voltage cycle that the arc-back occurs.

3. In combination, an electric valve means, means for rendering said electric valve means conducting and nonconducting during predetermined intervals and for subjecting said valve means to an inverse voltage cycle during each

of the normally nonconducting intervals, a capacitor, means for charging said capacitor in accordance with the inverse voltage cycle, and means responsive to the condition of charge of said capacitor upon the occurrence of an arc-back for indicating the time in the inverse voltage cycle that the arc-back occurs.

4. In combination, an electric valve means, means for rendering said electric valve means conducting and nonconducting during predetermined intervals and for subjecting said valve means to an inverse voltage cycle during each of the normally nonconducting intervals, a capacitor, means for charging said capacitor in accordance with the inverse voltage cycle impressed on said valve means, a second capacitor, means for transferring the charge from said first capacitor to said second capacitor upon the occurrence of an arc-back, and means for measuring the charge on said second capacitor to indicate the time in the inverse voltage cycle that the arc-back occurs.

5. In combination, a plurality of electric valve means, means for energizing said electric valve means to render said valve means alternately conducting and nonconducting in a predetermined sequence and for subjecting each of said valve means to an inverse voltage cycle during the normally nonconducting periods thereof, each of said electric valve means being subject to arc-back during said inverse voltage cycle, capacitance means associated with each of said plurality of electric valve means and having a charge and discharge circuit, current supply means connected to said charge circuit for charging said capacitance means, means including an electric discharge device interposed in the discharge circuit of said capacitance means and connected to be rendered conductive in response to the occurrence of an arc-back in said electric valve means for discharging said capacitance means, and means connected to be energized in accordance with an electrical condition of the discharge circuit of said capacitance means for determining the instant in the inverse voltage cycle of the faulty electric valve means at which arc-back occurs.

6. In combination, an electric valve means, means for rendering said electric valve means conducting and nonconducting during predetermined intervals and for subjecting said valve means to an inverse voltage cycle during each of the normally nonconducting intervals, said electric valve means being subject to an abnormal operating connection during said inverse voltage cycle, a capacitor, means for charging said capacitor between predetermined limits during each inverse voltage cycle, means for discharging said capacitor upon the occurrence of said abnormal operating condition, and means responsive to the charge on said capacitor at the instant that an abnormal operating condition of said valve means occurs for indicating the time in the inverse voltage cycle that said abnormal condition occurs.

7. In combination, an electric valve means, means for rendering said electric valve means conducting and nonconducting during predetermined intervals and for subjecting said valve means to an inverse voltage cycle during each of the normally nonconducting intervals, a capacitor, means for charging said capacitor in accordance with the inverse voltage cycle impressed on said valve means, a second capacitor, an electric valve including a control member intercon-

necting said capacitors, means for rendering said electric valve conductive upon the occurrence of an abnormal condition of said electric valve means for transferring the charge from said first capacitor to said second capacitor upon the occurrence of said abnormal condition, and means for measuring the charge of said second capacitor to indicate the time in the inverse voltage cycle that the abnormal condition occurs.

8. In combination, an electric valve means, means for rendering said valve means conductive and nonconductive during predetermined intervals and for subjecting said valve means to an inverse voltage cycle during each of the normally nonconducting intervals, a record chart, means for moving said chart at a predetermined speed relative to the frequency of the voltage applied to said valve means, means operatively associated with said record chart for indicating a reference point for said chart corresponding to the instant of initiation of said inverse voltage cycle, and means for recording on said chart the instant that an arc-back in said valve means occurs relative to said reference point.

9. In combination, an electric valve means, means for rendering said electric valve means conducting and nonconducting during predetermined intervals and for subjecting said valve means to an inverse voltage cycle during each of the normally nonconducting intervals, a record chart, means for moving said record chart at a predetermined speed relative to the frequency of the voltage applied to said valve means, means operatively associated with said record chart for indicating a reference point for said chart corresponding to the instant of initiation of said inverse voltage cycle of said electric valve means, and means including means for producing a voltage impulse upon the occurrence of an abnormal condition in said electric valve means for indicating on said chart the instant in the inverse voltage cycle relative to said reference point that said abnormal condition occurs.

10. In combination, a plurality of electric valve means, means including an alternating-current circuit for energizing said electric valve means to render said valve means alternately conducting and nonconducting in a predetermined sequence, a record chart, means for moving said record chart in a predetermined timed relation with the frequency of said alternating-current circuit, means associated with said chart for indicating on said chart the instant that any of said valve means arcs back, and additional means for recording on said chart the instant of initiation of said inverse cycle so as to establish a point of reference on said chart for determining the first electric valve means to arc back.

11. In combination, a plurality of electric valve

means, means including an alternating-current circuit for energizing said electric valve means to render said valve means alternately conducting and nonconducting in a predetermined sequence, a record chart, means for moving said record chart in a predetermined timed relation with the frequency of said alternating-current circuit, a plurality of electrodes associated with said chart, means for impressing an impulse of voltage on a predetermined one of said electrodes when a corresponding one of said electric valve means arcs back, an additional electrode, and means for impressing an impulse of voltage on said additional electrode only when the first of said electric valve means arcs back.

12. In combination, an electromagnetic device having a closed core of substantially rectangular shape with two oppositely located legs of substantially smaller cross section than the remaining two oppositely disposed legs, a winding on each of said legs of smaller cross section, means for energizing said windings with unidirectional current to produce substantial saturation of said legs of smaller cross section, and a second winding on each of said legs of smaller cross section, means for connecting said second windings in parallel, and means responsive to said parallel connected windings for indicating a transient electrical condition in a conductor symmetrically located with respect to said legs of smaller cross section, said legs of larger cross section and said parallel connected windings operating to prevent operation of said transient-indicating means in response to stray magnetomotive forces not symmetrically located with respect to said legs of smaller cross section.

13. In combination, a plurality of circuits normally subjected to a cyclically recurring electrical condition, a plurality of electromagnetic devices arranged one with each of said circuits and each electromagnetic device including a core structure and a first winding on each of said core structures and each winding being coupled with one of said circuits, a plurality of indicating means each individual to one of said circuits, means connecting said first windings respectively with said indicating means, a second winding on each of said core structures, a direct-current supply means, means connecting said second windings in series and for energization from said direct-current supply means, and means responsive to a transient voltage in the series direct current circuit of said second windings resulting from a voltage induced in one of said second windings in response to a transient voltage in one of said circuits for indicating the first transient voltage to occur in one of said circuits.

BURNICE D. BEDFORD.