Aug. 2, 1938. G. F. METCALF 2,125,799

CIRCUITS FOR ARC-BACK SUPPRESSION

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Fig. 1.

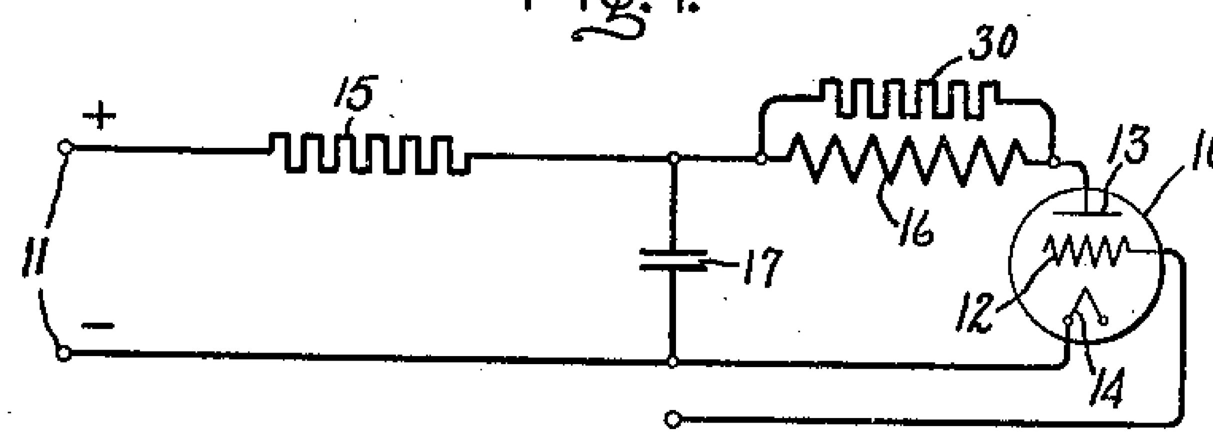

Fig. 4.

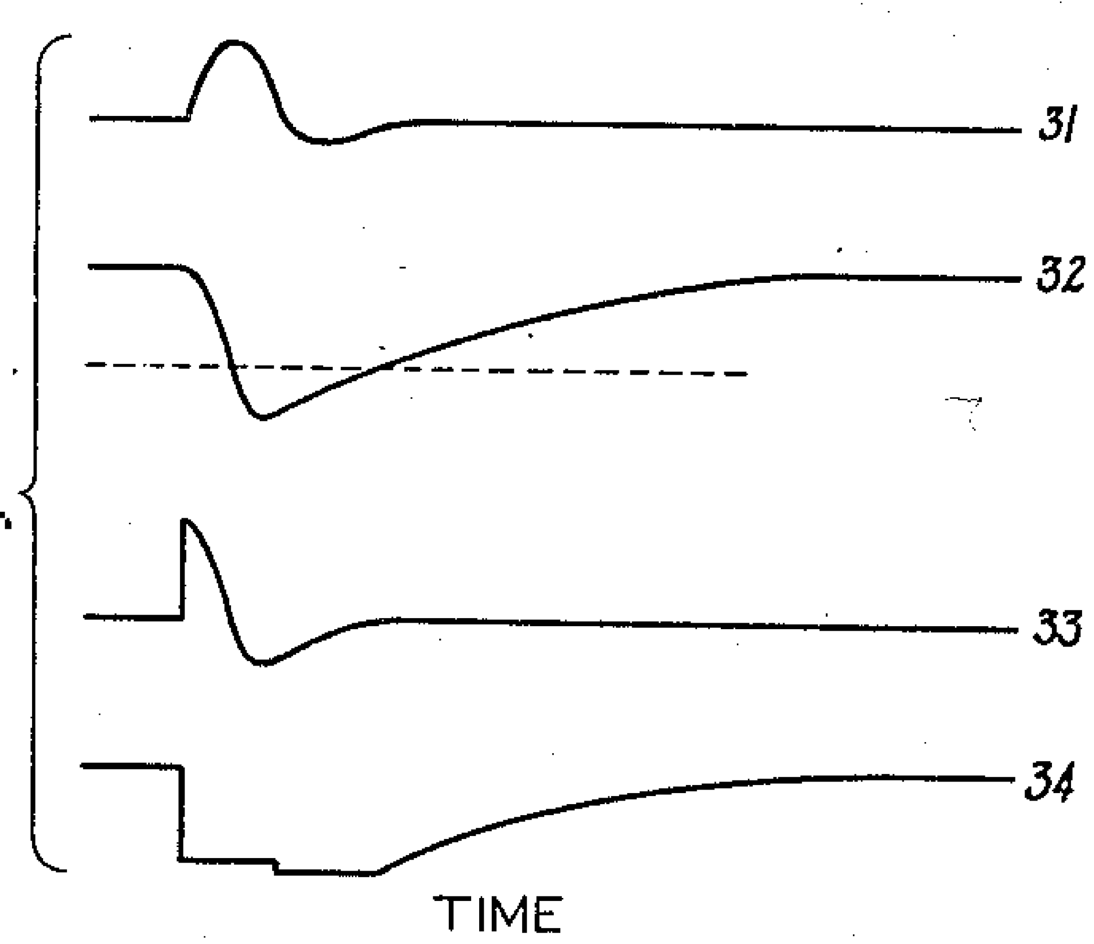

Fig. 2.

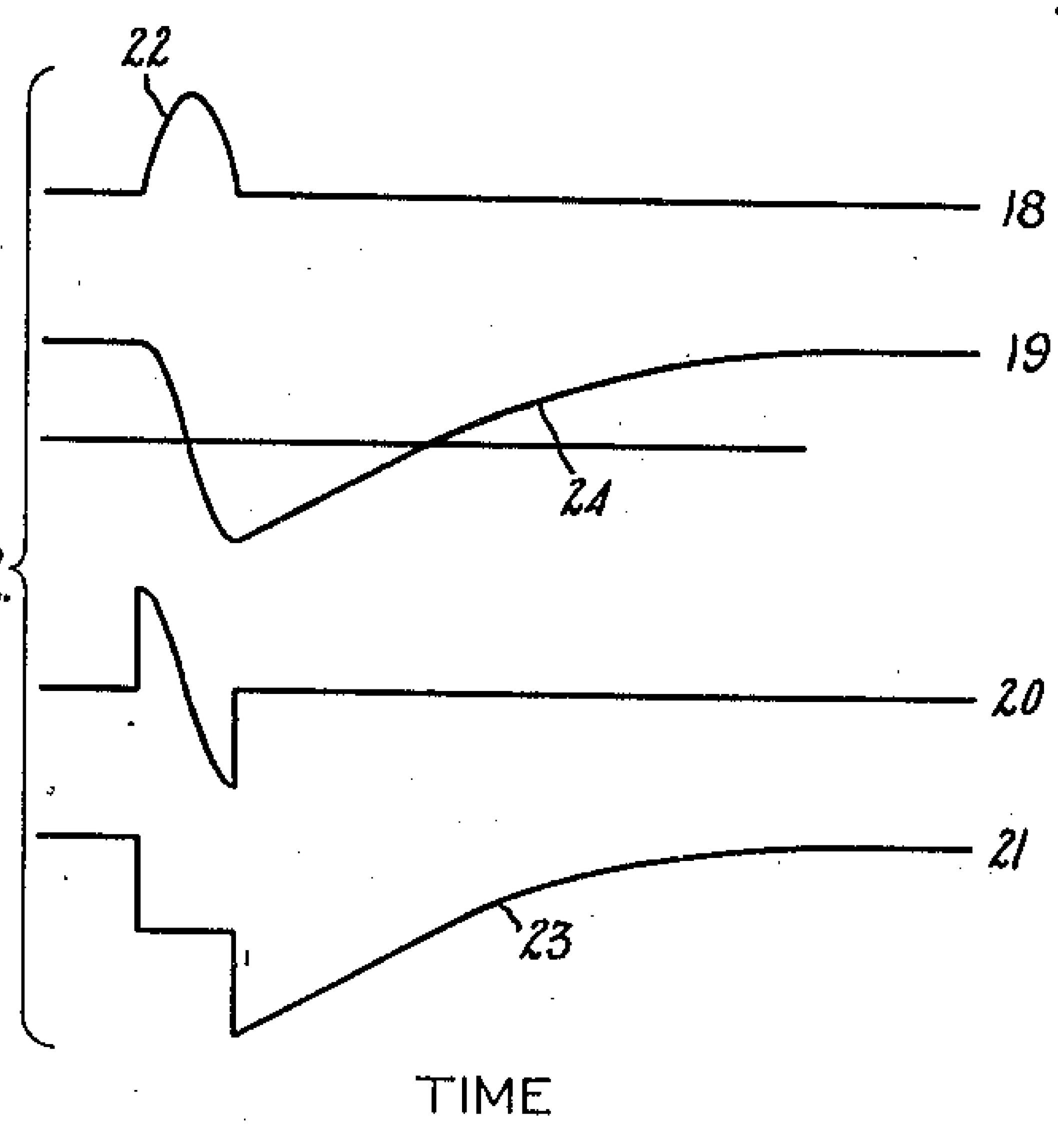

Fig. 5.

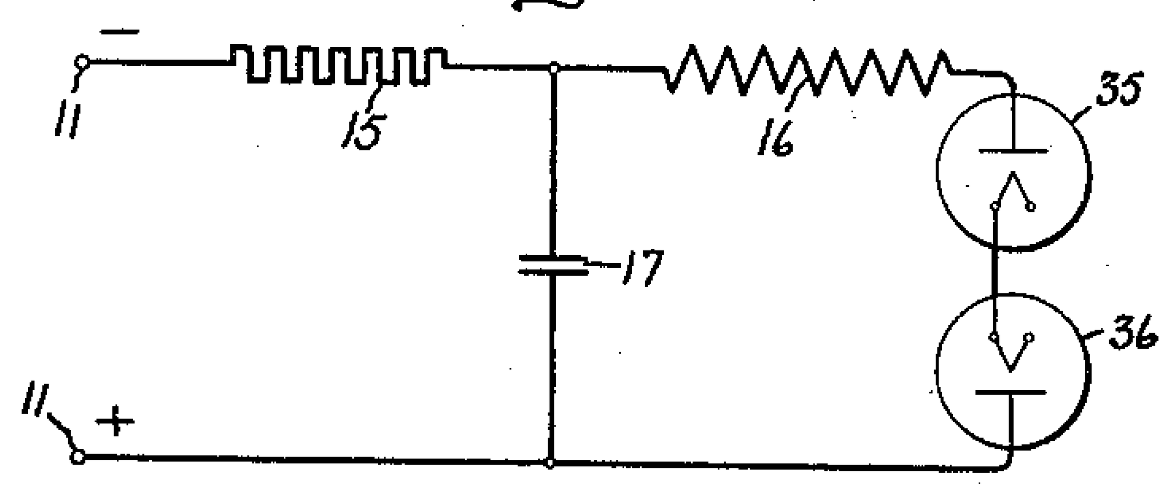

Fig. 3.

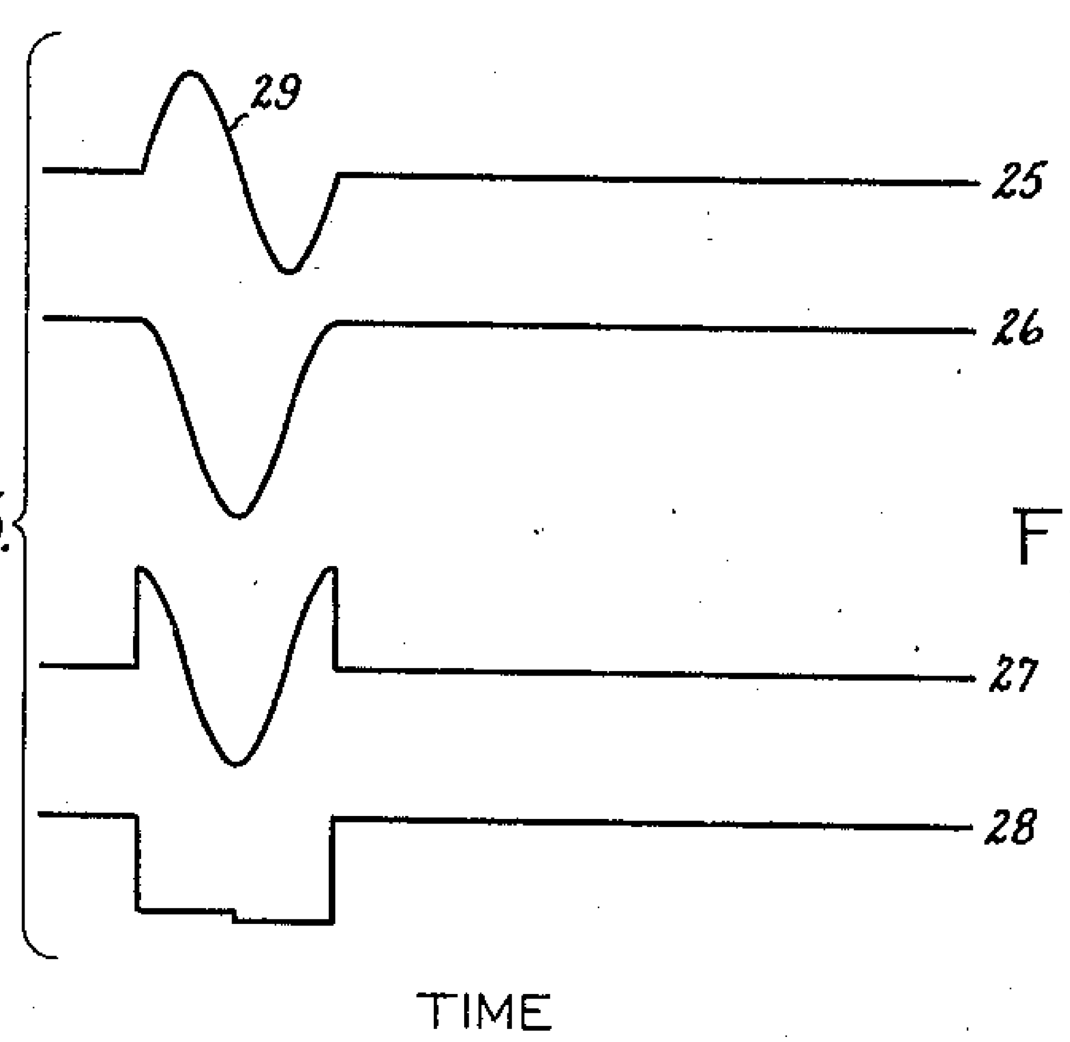

Fig. 6.

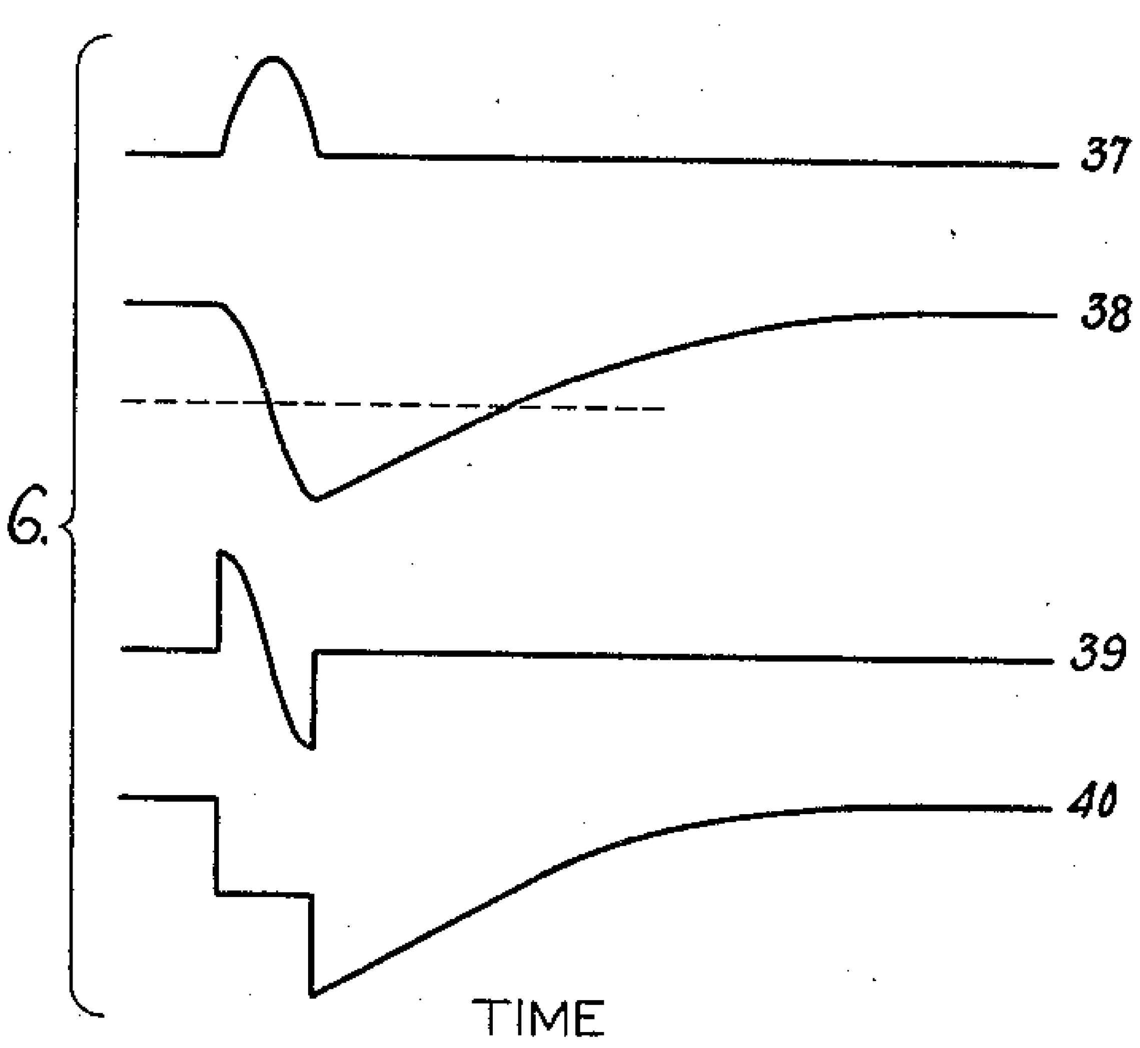

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Fig. 10.

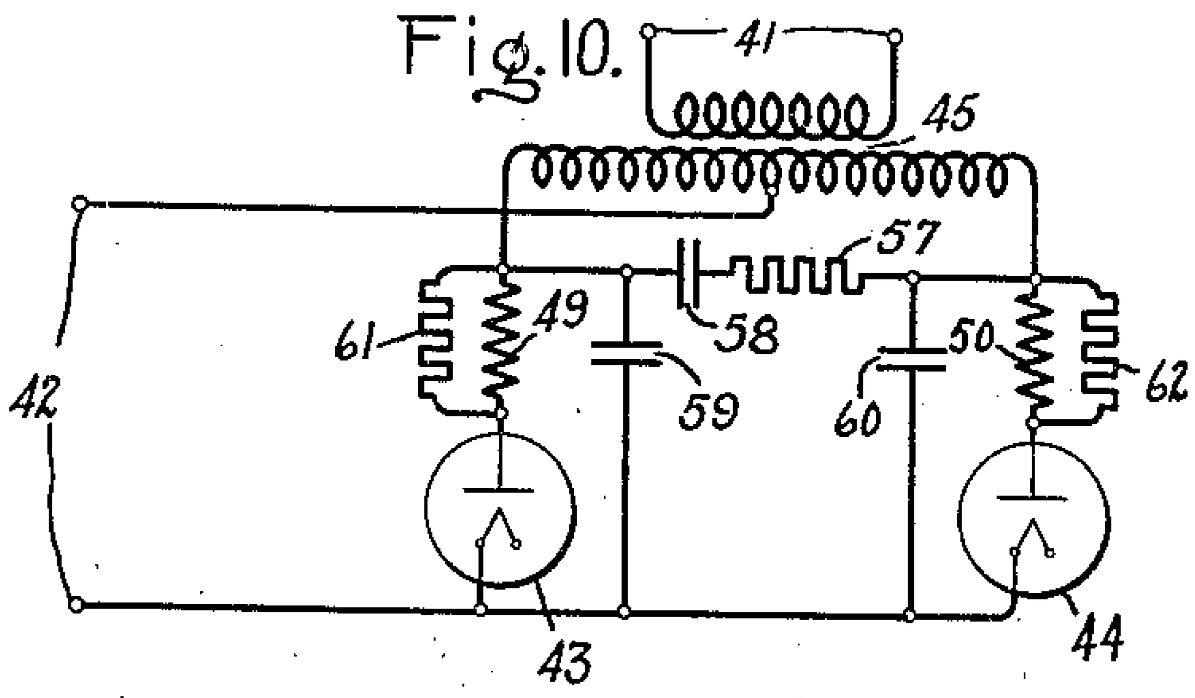


Fig. 8.

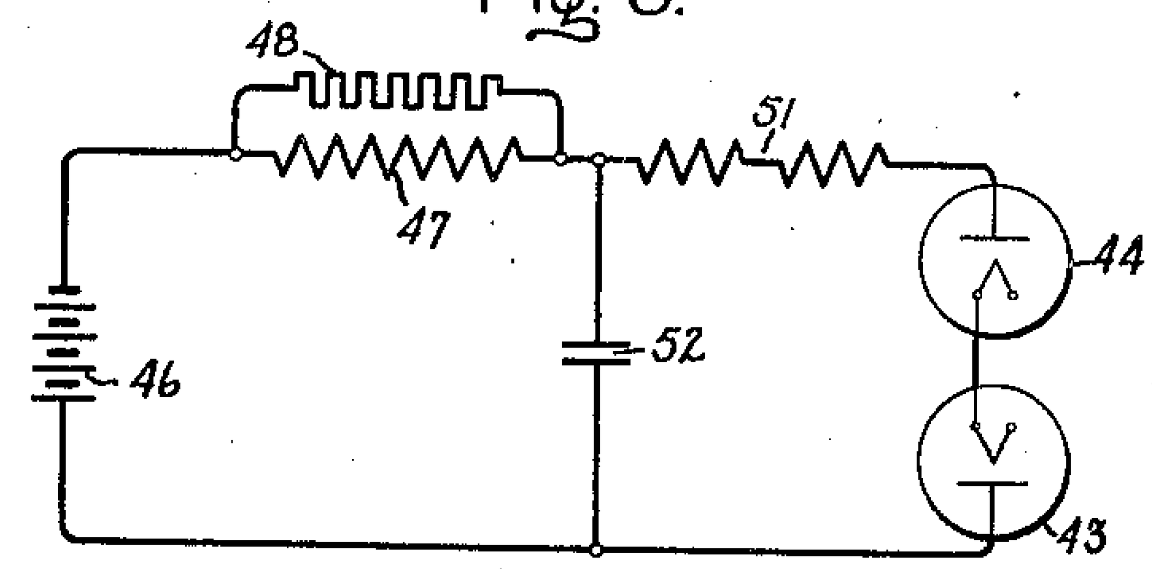


Fig. 9

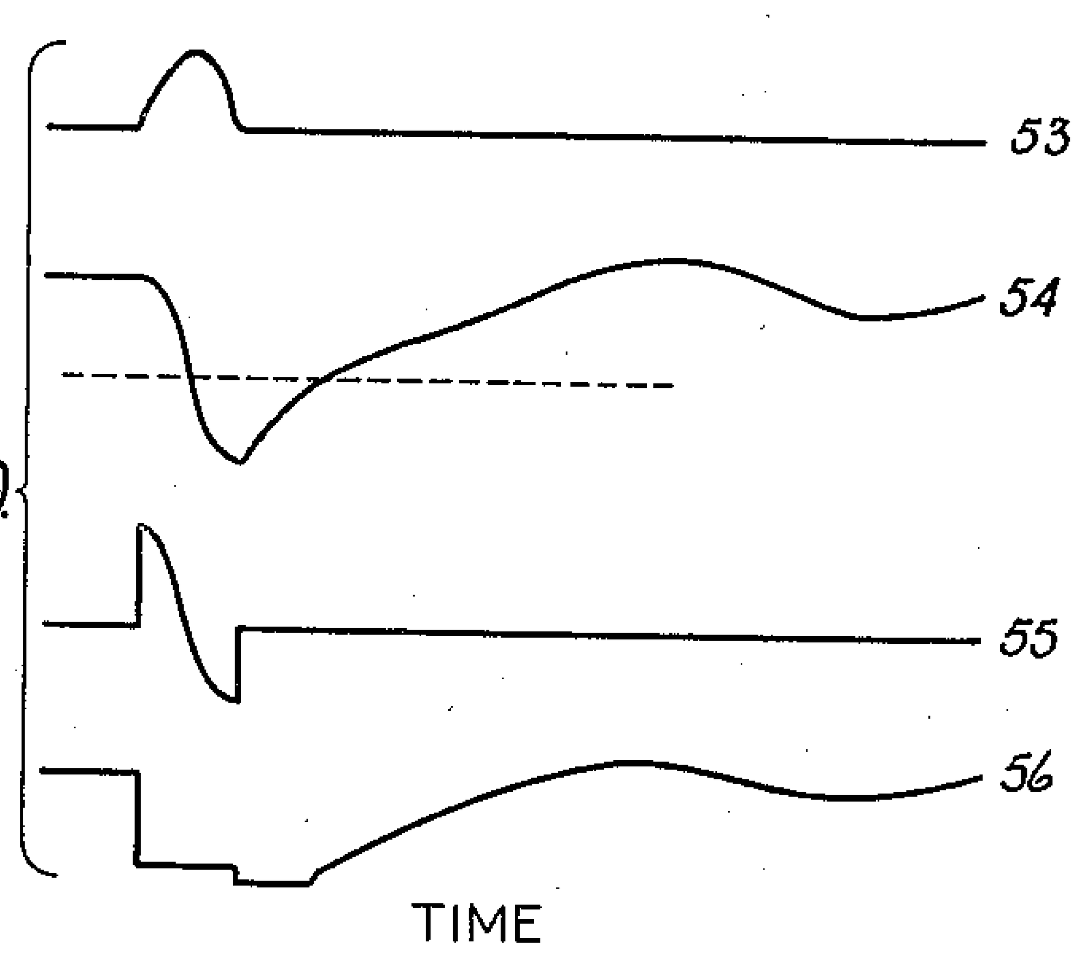
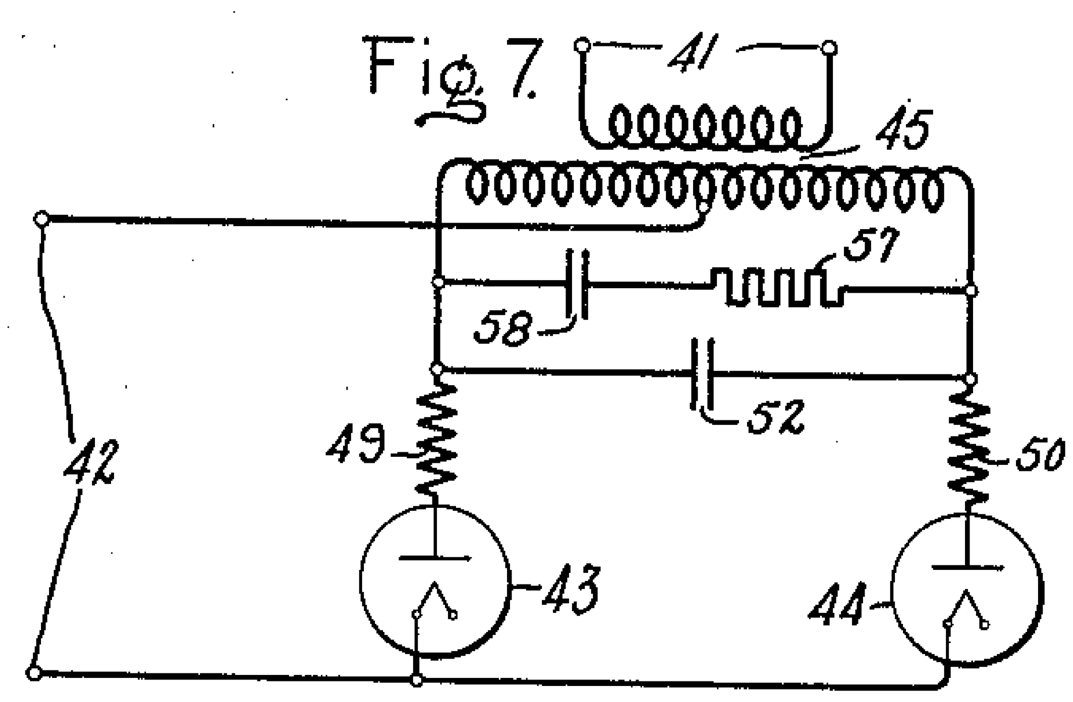


Fig. 7.



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Patented Aug. 2, 1938

2,125,799

UNITED STATES PATENT OFFICE

2,125,799

CIRCUITS FOR ARC-BACK SUPPRESSION

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Application April 16, 1936, Serial No. 74,806

6 Claims. (Cl. 175—363)

My invention relates to electric systems, for example rectifier or inverter systems including vacuum or gas-filled tubes and particularly to such systems which are subject to arc-back. One of its objects is to provide for systems of this character simple and inexpensive circuit arrangements such that damage upon occurrence of arc-back is prevented without affecting the operation of the system.

When an arc-back occurs between the electrodes in a high vacuum tube it has been found that the cathode spot at which the arc-back originates is extinguished in less than one microsecond after the current has been reduced below a certain critical value, and that the tube will then insulate to at least as high a voltage as before the arc-back occurred. This is due to the rapid cooling of the electrode at the point of emission and to the rapid movement of the metallic vapors away from the region of the arc. If, however, the arc-back occurs in the presence of a gas, as it does in the operation of a mercury cathode tube or of a hot-cathode vapor-filled tube, it is not only necessary to extinguish the cathode spot at which the arc-back originates, but also the ions formed in the gas must be removed before high voltage may be again applied. This process takes a much longer time than in the case of the vacuum tube. This time is determined by the gas pressure, the current density, the geometry of the tube, and a number of other factors, and is of the order of 100 micro-seconds.

With these factors in mind it is seen that if circuits were designed which would remove the voltage from the gas-filled tube for a short interval of time after the instant of starting of the arc-back, the main destructive effects of the arc-back would be obviated. In accordance with my invention I have developed circuit arrangements which operate in this manner but which do not affect the operation of the rectifier or inverter apparatus at commercial frequencies. In carrying my invention into effect, small amounts of inductance and capacity are added to conventional rectifier and inverter circuits. In order that an arc-back may be interrupted at the proper instant by a circuit arrangement of this type, it is only necessary that the values of the inductance, capacity, and damping resistance be chosen to correspond with a time longer than the de-arcing time of the tube, but no longer than and preferably substantially less than the time period of a half cycle of the voltage in the oscillatory branch of the system.

My invention will be better understood from the following description when considered in connection with the appended drawings and its scope will be set forth in the appended claims.

Referring to the drawings, Fig. 1 is a circuit diagram of an electric system, including a gas-filled tube, illustrating the principles of my invention; Figs. 2, 3 and 4 show curves illustrating the operation of the system of Fig. 1 under different circuit conditions; Fig. 5 is a circuit diagram of an electric system, including gas-filled tubes in series, further illustrating the principles of my invention; Fig. 6 shows curves illustrating the operation of Fig. 5; Figs. 7 and 8 are circuit diagrams of an electric system illustrating the application of the principles of the invention to alternating current circuits; Fig. 9 shows curves illustrating the operaton of the electric system shown in Figs. 7 and 8; and Fig. 10 is a circuit diagram of an electric system illustrating a further application of the principles of the invention to alternating current circuits.

Fig. 1 shows diagrammatically an inverter comprising an arc discharge device such as a vapor electric device or gas-filled tube **10** connected to a direct current circuit **11** and having a control electrode or grid **12** to permit initiation of the load current between anode **13** and cathode **14**. The method and means employed, in accordance with my invention, to interrupt arc-back current and to allow relatively slow build-up of the anode voltage after interruption of the arc-back will be more clearly understood by an analysis of the simple one-tube inverter of Fig. 1.

In the above inverter the discharge through tube **10** is initiated by the application of a positive potential to the grid **12**, the anode **13** being positive. When the charging resistance **15** in the direct current circuit **11** is large compared to the impedance of the oscillatory branch including inductance **16** and capacitance **17**, the forms of the voltage and current waves are substantially as shown in Fig. 2, in which curves **18** to **21** designate respectively the current through tube **10**, the voltage across condenser **17**, the voltage across inductance **16**, and the voltage across tube **10**. From these curves it is seen how the tube current, initiated by the positive grid potential and indicated by **22** of curve **18**, is interrupted, and how, after the current interruption, the forward voltage, as indicated at **23** of curve **21**, is slowly applied to the tube by the charging of the condenser **17** through resistance **15**, as indicated by **24** of curve **19**.

If, however, instead of the anode 13 being positive and the discharge being initiated by the grid potential, the anode were negative and the discharge were caused by arc-back, the transient would be, in general, the same as indicated for the operation of the simple inverter except for the recovery of the charge on condenser 17. For the latter assumed condition of the circuits of Fig. 1, that is, of negative anode and of a discharge caused by arc-back, the wave forms of the voltage and current would be as shown in Fig. 3, wherein the curves 25 to 28 correspond to curves 18 to 21 of Fig. 2. From Fig. 3 it is seen that although the arc-back current, indicated by 29 of curve 25, has been interrupted, the full voltage is applied to the tube in a short interval of time and that even during this interval a discharge has occurred through the tube in the forward direction. This sudden application of full voltage may be overcome by either of two methods or by a combination of the two.

In one method the inductance 16 may be shunted by a resistance, as 30, of such value that all of the energy stored in capacitance 17 is dissipated by the end of one complete cycle of the oscillatory circuit. The operation of the system will then be as illustrated in Fig. 4 wherein curves 31 and 34 correspond respectively to curves 18 to 21 of Fig. 2.

In the other method the arc-back discharge is caused to occur through two tubes 35, 36 in series as shown in Fig. 5, the operation of the circuit of Fig. 5 being as illustrated by the curves of Fig. 6 wherein the curves 37 to 40 correspond respectively to curves 18 to 21 of Fig. 2.

In the application of the principles of the invention, as illustrated with respect to the circuit of Fig. 1, to alternating current circuits it is necessary to replace the charging resistance 15 by the equivalent short-circuit impedance of the transformer supplying the power to the circuit in case the system is a rectifier system, and to select values of capacity and inductance such that the entire transient occurs during a time interval which is small compared to the time interval of a half cycle of the power supply frequency. The substitution of inductance for the charging resistance 15 results however in added complexity as the branch including this inductance may then become oscillatory and may subject the arc discharge device or tube to an inverse voltage as much as twice the original value. This is well illustrated by an analysis of the operation of a conventional full wave rectifier circuit having capacity and inductance added, in accordance with my invention, to interrupt arc-back current and thereafter to allow the slow rise in anode voltage necessary to successful commutation of the arc-back.

In Fig. 7 such a full wave rectifier system is shown comprising alternating current circuit 41 and direct current circuit 42 between which power is transferred through arc discharge devices, such as a pair of vapor electric devices or gas-filled tubes 43, 44, and supply transformer 45. In this typical system the constants were chosen to give a de-arcing time of 100 micro-seconds. The transformer 45 had a rating of 110–440 volts, 60 cycles, 5 kv-a. with 5 per cent short-circuit impedance.

In order to simplify the study of this typical system during the period of an arc-back, reference may be had to Fig. 8 in which the alternating supply voltage from transformer 45 is replaced by a battery 46 and the leakage reactance of the transformer 45 by the inductance 47. The resistance 48 in shunt with inductance 47 is equal to the combined damping of the load and transformer losses. As the path of the arc-back current is through both tubes, the series inductances 49, 50 of Fig. 7 are grouped as one inductance, 51 in Fig. 8. Calculation of the constants for the circuit shown in Figs. 7 and 8 resulted in a valve of .00515 henry for the leakage inductance 47, and a value of 3.88 microfarads for the capacity 52, which was somewhat larger than needed in order to provide a factor of safety. The value of the series inductance, 49, 50 of Fig. 7 or 51 of Fig. 8, is chosen arbitrarily except that it must be between a maximum such that the circuit of this series inductance and capacity 52 is oscillatory, and a minimum such that the peak arc-back currents are not excessive. Experience has shown this value to be from $\frac{1}{20}$ to $\frac{1}{50}$ that of the value of the leakage inductance 47 of the supply transformer 45 in the typical system above described in connection with Figs. 7 and 8. The value of the series inductance was chosen as approximately 170 microhenries. The calculation of similar constants in polyphase circuits follows the same general method as for the full-wave circuit above described, the value of the leakage reactance being determined in the same way except that only the transformer windings which are short-circuited by the arc enter into the calculation of leakage reactance.

Fig. 9 shows voltage and current curves illustrating the operation of the system above described in connection with Figs. 7 and 8, the curves 53 to 56 corresponding respectively to curves 37 to 40 of Fig. 6, for example. It will be seen that the curves of Fig. 9 are similar to those of Fig. 6 which illustrate the operation of the system shown in Fig. 5 comprising two arc discharge devices or tubes in series. The curves of Fig. 9, illustrating the operation of the system of Figs. 7 and 8, are exactly what are to be expected from the operation of the similar system of Fig. 5 except that in Fig. 9 the recovery voltage across the tubes is seen to be oscillatory and its rise is slightly accelerated by the discharge of the inductance of the load circuit 42 into capacitance 52 during the time of negative voltage on the tube 43. In certain cases when tubes are operated near their maximum voltage rating the over-voltage to which the tube is subjected on recovery of tube voltage may prove sufficient to initiate a new arc. This condition may be remedied by the addition of a damping resistance 57 (Fig. 7) across the transformer windings 45. A condenser 58 in series with the additional resistance 57 reduces the steady or continuous power loss and yet permits damping of the transient.

In Fig. 10 the circuit arrangements are similar to those of Fig. 7 except that in Fig. 10 commutating capacitances, 59, 60, are provided in shunt with each of the tubes 43, 44 and damping resistances, 61, 62, are provided in shunt with the series inductances 49, 50. Calculations similar to those employed in connection with the circuits shown in Fig. 7 may be made in order to determine the constants for the circuits of Fig. 10.

It is to be noted that the de-arcing time of any particular arc discharge device or tube is determined by a number of factors of which the most important is the voltage at the moment of the arc-back. This one factor may cause the de-arcing time to vary from one micro-second to over 100 micro-seconds and in general it is in direct proportion to the value of anode voltage. The effect of variations in arc-back current, vapor pressure, and condition of the anode surface is much more difficult to evaluate. For this reason it is best to measure the current constants under actual operating conditions in order to determine the proper values of inductance and capacity for successful commutation of arc-back. The tube design factor which is the most important is the spacing between anode and cathode or between anode and grid if the grid is connected to the cathode. The condition of the anode surface also plays a major part as is evidenced by the fact that tubes in which the anode has a heavy barium coating require a much longer de-arcing time.

My invention has been described herein in particular embodiments for purposes of illustration. It is to be understood, however, that the invention is susceptible of various changes and modifications and that by the appended claims I intend to cover any such 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 an electric system comprising an arc discharge device having an anode and a cathode, and means to impress an alternating supply voltage upon said anode, said device being subject to the occurrence of arc-back therein, means to interrupt said arc-back within a time period beginning with the instant of initiation of said arc-back which is less than the time period of a half cycle of said alternating voltage, said means including an oscillatory circuit such that immediately upon initiation of an arc-back in said device a transient is produced in said system by said oscillatory circuit which continues after said initiation during a time period only which is small relative to the time period of a half cycle of said alternating voltage.

2. In an electric system comprising a plurality of arc discharge devices and an inductance connected to said devices to impress an alternating voltage thereon, said devices being subject to the occurrence of arc-back therein, means to interrupt said arc-back within a time period beginning with the instant of initiation of said arc-back which is less than the time period of a half-cycle of said voltage, said means comprising an oscillatory circuit including the leakage reactance of said inductance and capacitance associated with said inductance, the constants of said oscillatory circuit being such that immediately upon initiation of an arc-back in one of said devices a transient is produced by said oscillatory circuit in said system which continues after said initiation during a time period only which is substantially less than the time period of a half cycle of said alternating voltage.

3. In an electric system comprising an alternating current circuit, a direct current circuit, and means to transfer power between said circuits comprising a plurality of arc discharge devices and an inductance connected thereto, an oscillatory circuit to interrupt arc-backs in said devices within a time period beginning with the instant of initiation of an arc-back which is less than the time period of a half-cycle of said voltage, said means comprising the leakage reactance of said inductance and capacitance means associated with said inductance, the constants of said oscillatory circuit being such that immediately upon initiation of an arc-back in one of said devices a transient is produced by said oscillatory circuit in said system which continues after said initiation during a time period only which is not longer than the time period of a half cycle of the voltage in said alternating current circuit.

4. In an electric system comprising an alternating current circuit, a direct current circuit, and means to transfer power between said circuits comprising a plurality of arc discharge devices and an inductance connected to said devices, an oscillatory circuit to interrupt arc-back in said devices within a time period beginning with the instant of initiation of an arc-back which is less than the time period of a half-cycle of said voltage, said means comprising the leakage reactance of said inductance, capacitance means associated with said inductance, and inductance means in series with said devices and said first named inductance, the constants of said oscillatory circuit being such that immediately upon initiation of an arc-back in one of said devices a transient is produced in said system by said oscillatory circuit which continues after said initiation during a time period only which is not longer than the time period of a half cycle of the voltage in said alternating current circuit.

5. In an electric system comprising an alternating current circuit, a direct current circuit, and means to transfer power between said circuits including a plurality of arc discharge devices and an inductance connected thereto, an oscillatory circuit to interrupt arc-back in said devices comprising the leakage reactance of said inductance, capacitance means associated with said inductance and inductance means in series with said devices and said first named inductance, and damping means including a resistance and a capacitance in series connected across said first named inductance.

6. In an electric system comprising an alternating current circuit, a direct current circuit, and means to transfer power between said circuits including a plurality of arc discharge devices and an inductance connected thereto, oscillatory circuit means to interrupt arc-back in said devices comprising the leakage reactance of said inductance, a plurality of inductances each in series with said first named inductance and a different one of said devices, a plurality of capacitances each connected across a different pair of said devices and said last named inductance, and a plurality of damping resistances each connected across a different one of said last named inductances.

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