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ALTERNATING CURRENT ARC POWER SOURCE

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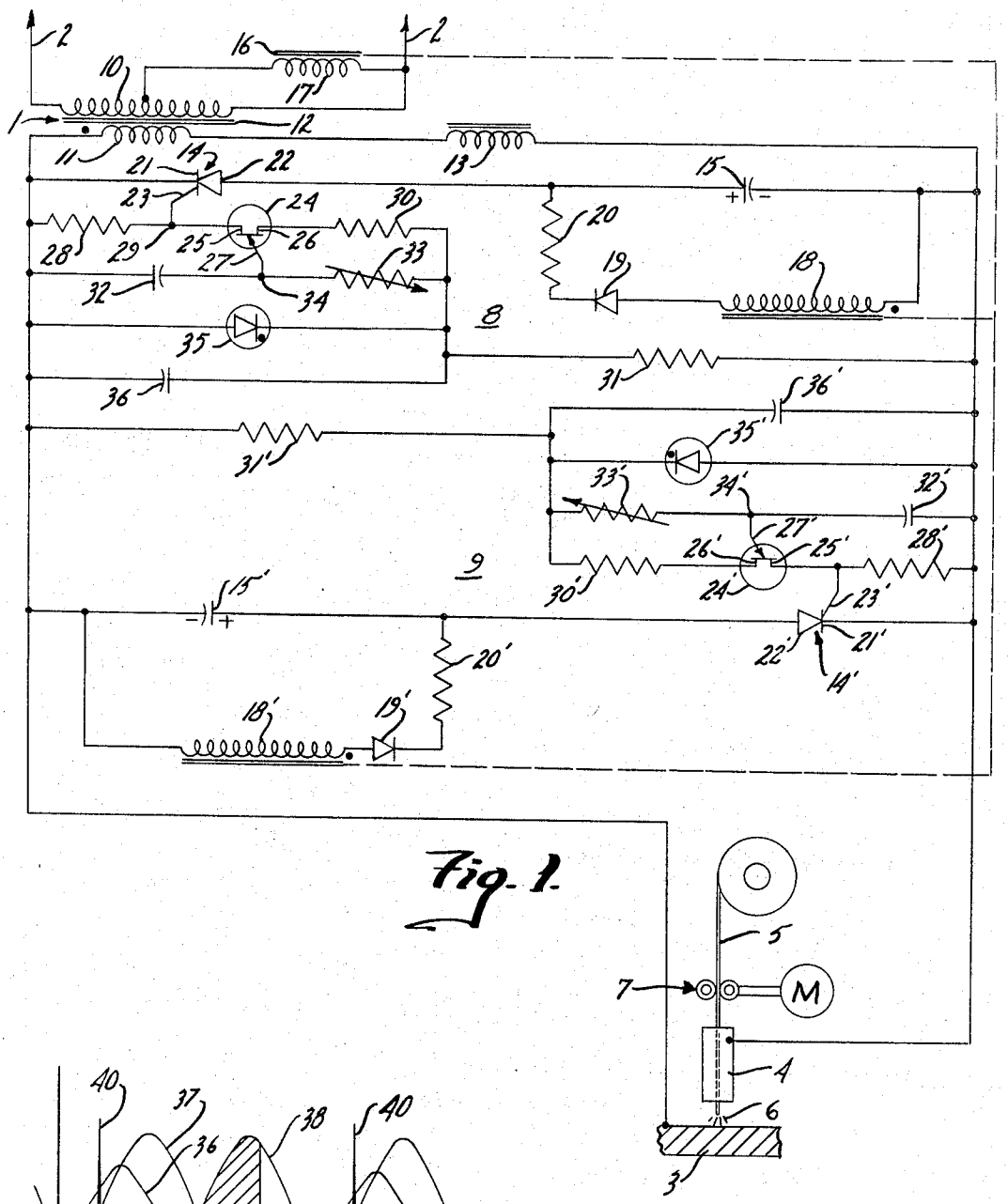


Fig. 1

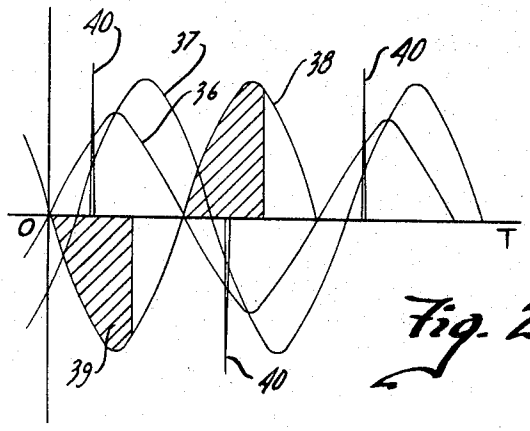


Fig. 2

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ALTERNATING CURRENT ARC POWER SOURCE

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ABSTRACT OF THE DISCLOSURE

The invention involves an arc current supply system having a pair of surge stabilizing circuits. These circuits each have a pulse capacitor and triggered switching means. Each surge stabilizing circuit facilitates arc reignition during welding. These circuits operate in conjunction with an alternating current applied to the electrode and the workpiece being welded.

Welding arcs and similar high current arcs for melting and other processing have been established with either alternating currents or direct currents depending upon the particular work requirements. Such arcs may employ a consumable electrode or a nonconsumable electrode. Further, the power source may be of the constant current variety having a drooping voltage versus current characteristic or the constant potential variety having a relatively flat characteristic. The constant potential variety has been found to be preferred for many applications.

Alternating current power has certain advantages from simplicity of basic equipment. However, in alternating current arcs, the current at each reversal or half cycle passes through zero and the arc must be actually reignited. This has introduced severe complications in the provision of a stable alternating current arc. In order to stabilize an alternating current arc for welding and the like, various suggestions have been made. The addition of certain emissive agents to a consumable electrode and/or to the arc aids reignition at each zero crossover and helps stabilize the alternating current arc. Additionally, surge or pulse circuits have been added in the output circuit to provide additional ignition power during the periods of reignition. Thus, high frequency circuits have been suggested. These have certain disadvantages from the standpoint of expense, complexity and regulation because of the high frequency signal radiation. Additionally, capacitance surge and similar discharge pulse circuits have been suggested wherein a striking pulse is impressed in parallel across the arc in the vicinity of the current at the time it is passing through zero; for example, as shown in U.S. Patent 2,891,196.

In alternating current arc welding and the like, a relatively constant potential power source rather than the constant current source is desirable. Generally, it has been found necessary and desirable to shift the arc voltage with respect to the current such that a voltage is available to restrike the arc as the current passes through zero. Normally, this will be done by the insertion of a suitable reactor or other inductance in series with the output leads. Although this has a very desirable result as far as restriking is concerned, it creates a drooping characteristic. The transformer output thus has a characteristic somewhat similar to constant current units. This requires a greater rated power transformer with the resulting additional expense as well as the corresponding undesirable arc characteristics for certain applications.

The present invention is particularly directed to an arc power supply having a pulse or surge circuit incorporated as a part of the output of the main current circuit and producing an accurately timed reignition pulse during the initial portion of each half cycle. The present invention is particularly directed to a relatively simple, inexpensive and reliable circuit which can be employed with a constant potential power source to produce and maintain an exceedingly stable alternating current welding arc.

The present invention generally employs a pair of capacitive pulse circuits connected in parallel with the power source, and in series with the welding arc, each of which includes a gate controlled or triggered rectifier connected in series with a surge or pulse capacitor and a means to trigger the rectifiers to provide controlled discharge of the energy stored in the capacitors into the arc. The rectifiers are oppositely polarized such that one aids reignition during the positive half cycle and the other acts during the negative half cycle. The capacitors are sequentially and alternately charged by the alternate half-cycles of a current to a relatively high voltage, generally four to five times the normal arc voltage. When the controlled rectifier is fired, the corresponding capacitor injects a high voltage pulse into the circuit, preferably during the beginning or initial portion of each half cycle of the welding current. The controlled rectifiers carry only a very minimum amount of current for a very short time cycle and consequently small and inexpensive controlled rectifiers can be employed.

In a preferred construction, a surge transformer is provided having its primary connected across a portion of the main welding transformer primary and having a pair of secondaries each of which is connected in parallel with a corresponding surge or pulse capacitor. Suitable diodes are connected in series with each of the surge secondaries and polarized to oppositely charge the two capacitors and prevent discharge of the capacitor through the secondary during the opposite half cycles. Additionally, a unijunction timing circuit is connected across the welding power lines to periodically generate a firing pulse to the corresponding rectifier. The unijunction timing unit includes a storage means charged from the main power lines in synchronism with the charging of the corresponding capacitor. The timing is set to trigger the controlled rectifier at the immediately next succeeding half cycle and thus the capacitor is discharged in aid of the corresponding main welding half cycle. Generally, unijunction transistor timing circuits employing capacitor timing means have a tendency to discharge during the terminal portion of the timing half cycle which tends to fire the rectifier just prior to the zero crossover point and therefore prior to the initial half cycle in which it is to provide an aiding voltage pulse. In accordance with the present invention, a short additional timing delay means is inserted in the timing circuit to delay the firing of the controlled rectifier junction and thereby insure firing during the initial portion of the next half cycle. Although it may not occur precisely at the zero crossover point, the pulse will always be early enough to provide stability without possible complete loss which may occur if exact zero crossover synchronism were attempted.

The drawing furnished herewith illustrates the above

advantages and features of the present invention as well as others which will be clear to those skilled in the art.

In the drawing:

FIG. 1 is a schematic circuit diagram of an alternating current constant potential arc welding source constructed in accordance with the present invention; and

FIG. 2 is a voltage and current versus time trace showing the main welding voltage and current, the surge charging current and the high voltage pulses.

Referring to the drawing and particularly to FIG. 1, a single phase arc welding system is shown including a single phase, constant potential arc welding transformer **1** connected to a set of incoming power lines **2**. The output of the transformer **1** is connected to a work member **3** and to an electrode nozzle **4** through which a consumable electrode **5** is fed toward the work **3**. The transformer **1** provides power across the work member **3** and the electrode **5** to establish and maintain an alternating current welding arc **6**. Electrode drive means **7** are coupled to the electrode **5** to continuously feed the consumable electrode **5** to the arc **6**.

The electrode feed and current transfer mechanism is shown diagrammatically as many different designs might be used which will be clear to those in the welding art.

The voltage impressed across and the current through arc **6** is an alternating current having alternate positive and negative half cycles. At the crossover point in the arc current, the arc **6** must actually be reignited with current flow in the opposite direction. In accordance with the illustrated embodiment of the invention, pulse or surge sources **8** and **9** are sequentially connected in series across the arc **6** and are adapted as hereinafter described to periodically provide a high voltage pulse during the initial portion of each successive half cycle of the main welding current and voltage.

More particularly, the main welding transformer **1** includes a primary winding **10** connected to the incoming power lines **2**. A low voltage secondary **11** is close coupled to the primary winding **10** through a magnetic core **12** in accordance with any well known or desirable construction and provides an essentially constant output voltage for all load or arc current supplied to arc **6**. A stabilizing reactor or inductance **13** is connected in series in the one load line between the secondary winding **11** and the pulse sources **8** and **9** to assist in the maintaining and the stabilizing of the arc **6** and in particular to prevent complete extinction of the arc **6** during the transition from half cycle to the next half cycle. As in past practice, the reactor **13** serves to shift the voltage to precede the current and thereby maintains voltage available to strike the arc in the opposite direction as the current passes through zero. As hereinafter described, in the present invention, the value of the reactor **13** can be substantially reduced as a result of the interaction of the surge sources **8** and **9**, although it has been found that optimum results are obtained by maintaining some reactance in the circuit.

The surge sources **8** and **9** are similarly constructed and consequently the source **8** will hereinafter be described in detail with corresponding elements in source **9** identified by similar primed numbers for simplicity and clarity of explanation.

The surge source **8** includes a silicon controlled rectifier **14** connected in series with a surge capacitor **15** between the main welding current or load lines connected respectively to the work member **3** and the nozzle **4**. A charging transformer **16** includes a primary winding **17** connected across one half of the main primary **10** of the welding transformer **1**. A secondary winding **18** is magnetically coupled to the primary winding **17**, shown by a dashed coupling line, and connected in series with a diode **19** and a current limiting resistor **20** across the related surge capacitor **15**. The diode **19** provides a polarized charging source such that the capacitor **15** will be charged, as shown by the usual positive and negative signs, during a

selected half cycle of the alternating current input cycle. During the next half cycle, the diode **19** prevents discharging of the capacitor **15** through the secondary or the transfer of energy from the secondary winding **18** to the capacitor. The capacitor **15** therefore maintains its charged condition until such time as the corresponding silicon controlled rectifier **14** is fired to discharge the capacitor.

The silicon controlled rectifier **14** is a well known element including a cathode **21** connected to the one output line and having an anode **22** connected to the capacitor **15** which is connected to the opposite power line. A gate **23** of the rectifier **14** can fire the silicon controlled rectifier into conduction whenever the anode **22** is positive relative to the cathode **21** in accordance with well known operation of such devices.

The surge sources **8** also include a firing circuit connected to provide a properly timed pulse to the gate **23** for firing the silicon controlled rectifier **14** and discharging of the capacitor **15** during the initial portion of a half cycle having a polarity at the secondary **11** corresponding to the polarity of the charging capacitor **15**. As a result, the discharge of the capacitor **15** provides an aiding voltage pulse to the main welding transformer **1**.

The illustrated firing circuit employs a well known unijunction transistor **24** having base electrodes **25** and **26** and a trigger or gate electrode **27**. A biasing resistor **28** is connected to the load line and to the base electrode **25** with the junction **29** therebetween connected to the gate **23** of the silicon controlled rectifier **14**. A bias resistor **30** in series with a common resistor **31** is connected between the electrode **26** and the opposite load line. A timing capacitor **32** in series with an adjustable timing resistor **33** is connected between the load line and the resistor **31** and thus in parallel with the unijunction transistor **24** and resistors **28** and **30**. The trigger electrode **27** of the unijunction transistor **24** is connected to the junction **34** of capacitor **32** and resistor **33**. A "Zener" diode **35** or the like is connected in parallel with the timing capacitor **32** and the timing resistor **33** and is polarized to effectively short circuit the timing circuit during one half cycle and to limit the voltage across the timing circuit during the alternate or timing cycle. In operation, during the half cycle during which the diode **35** is reverse biased, current flows through the timing resistor **33** and the timing capacitor **32**. At a selected charge level the trigger junction **34** is at a level which causes the unijunction transistor **24** to conduct between electrodes **25** and **27** whereupon the capacitor **32** rapidly discharges through the trigger electrode **27**, main electrode **25** and the resistor **28**. This generates a firing pulse at the junction **29**. This will turn on the silicon controlled rectifier **14** and discharge the capacitor **15**.

Generally, in such timing circuits, the unijunction transistor **24** will fire during the terminal portion of the charging half cycle of the main welding power. A holding capacitor **36** is connected in parallel with the unijunction transistor **24** and its resistors **28** and **30** and acts to delay the firing. This prevents firing before the welding current has reached zero.

The surge source **9** is basically identical to source **8** except that the corresponding components are reversely connected with respect to the welding power lines and consequently the silicon controlled rectifier **14'** is fired during the next half cycle. The capacitor **15'** is charged during the half cycle that the capacitor **15** is discharged. During the next half cycle, the voltage relationship of all of the transformer secondaries is reversed and capacitor **15'** is discharged to aid the voltage of the welding secondary and the capacitor **15** is again charged.

Referring to FIG. 2, voltage and current versus time traces are shown. For purposes of illustration, the main welding transformer secondary **11** and surge secondaries **18** and **18'** are shown with a properly related instantaneous polarity at a voltage reversal or zero crossover by the

conventional dots at the instantaneously positive end of the secondaries. The typical curves of FIG. 2 are related to the above assumed polarities.

A voltage curve **36** is shown crossing the zero axis in a positive direction at a selected reference time. The current curve **37** is a similarly shaped sine curve which lags the voltage curve by a slight angle as a result of the inductance of reactor **13**. Thus, when the current curve **37** crosses the zero axis in the positive direction, the voltage curve has risen to provide some restriking voltage.

The illustrated degree of phase shift between curves **36** and **37** is exaggerated for purposes of clarity. Ideally, the shift should be minimized to maintain the flat characteristic of a constant potential machine. Although a slight shift is desirable, the present invention permits substantial minimizing thereof without causing arc instability. The related output current of the secondaries **18** and **18'** of the surge transformer **16** is shown by the sinusoidal curve **38** which is shown out of phase with the main transformer voltage by 180 degrees. The surge transformer **16** is connected to provide this 180° shift with respect to the main transformer **1**. During the positive half cycle of the main voltage curve **36**, the output of the surge transformer **16** provides a negative half cycle across the capacitors **15** and **15'**. In operation, the capacitor **15'** is charged as a result of the polarized connection of diode **19'** and reaches a fully charged value in slightly more than one half of the period of the negative half cycle as shown by the cross hatched area under the corresponding half cycle of curve **39**. The polarity will be as indicated.

The surge capacitor **15** was fully charged by the prior half cycle to the polarity indicated; that is, with the positive side connected through rectifier **14** to the positive going line connected to the corresponding end of the transformer secondary **11**.

The timing capacitor **32** and holding capacitor **36** were charged from the main welding transformer output by current from the power lead to the right of the drawing, resistor **31**, resistor **33** and capacitor **32** in parallel with capacitor **36** to the indicated polarity during the same half cycle that the main capacitor **15** was charged. At the terminal portion of the half cycle of the welding current trace **37**, the unijunction transistor **24** would be biased to conduct by the voltage at junction **34**. The holding capacitor **36** however delays the firing voltage for a short period until the main welding current curve **37** has reached or passed the zero current axis; at which time the voltage relationship is such that the timing capacitor **32** rapidly discharges through the transistor **24** and resistor **28** thereby generating a firing signal at junction **29** and firing the silicon controlled rectifier **14** to permit the rapid discharge of the capacitor **15**. Although the secondary **11** of transformer **1** has its positive side then connected to the cathode of rectifier **14**, the capacitor **15** which is at a much higher voltage establishes the anode **22** at a higher positive voltage such that rectifier **14** fires when the trigger pulse is applied to gate **23**.

The discharge of capacitor **15** generates a high voltage pulse or spike, shown at **40** in FIG. 2, which aids the main transformer voltage.

During this portion of the cycle, the polarity of the secondary **18'** and the associated diode **19'** is such that charging current flows to charge the main storage capacitor **15'** to the selected voltage and polarity which occurs during the cross hatched portion of the half cycle of curve **38**.

During the half cycle that capacitor **15** was discharged, current also flows through the timing circuit for rectifier **14'**. Thus, current flows from the left line, through resistor **31'** to the capacitor **36'** in parallel with the timing capacitor **32'**. The timing period is set by adjustment of resistor **33'** and selection of capacitor **36'** to fire transistor **24'** and thereby rectifier **14'** as the welding current of curve **37** goes in the opposite or negative direction in the illustration. The capacitor **15'** maintains the charged condition until the timing circuit during the next half cycle is energized to trigger silicon controlled rectifier **14'** and discharge the capacitor **15'**.

The surge sources **8** and **9** are thus alternately and sequentially charged and discharged in timed relation with the corresponding half cycles of the welding current to produce sharp triggering pulses **40** during the first few degrees of the corresponding alternating power cycles. For most applications, the pulses are established in the first five degrees of the half cycle of the welding current. The pulses preferably have a peak of 250 to 300 volts. However, capacitors provide an instantaneous current surge generally in the order of 400 amperes for a period about 50 microseconds. This instantaneous current surge provides sufficient heat energy to insure arc reignition.

In accordance with the present invention, it has been found that the stabilizing reactor **13** can be made relatively small and further that the amount of emissive agents supplied to the arc **6** can be substantially reduced while maintaining a highly satisfactory and stable arc which has heretofore required a large reactor and/or excessive amounts of emissive agents. The reduction in required emissive agents is of substantial significance as a practical matter in producing welding electrodes incorporating emissive agents. Where relatively substantial portions of emissive agents have been required in welding electrodes to provide a highly satisfactory arc, the uniformity of the distribution of the emissive agents within the electrode was found to have a very marked effect on the arc.

In practice, the arc may vary as much as ⅛ inch in length with electrodes having a substantial amount of unevenly distributed emissive agents or material. Although the arc will appear to be very stable, it has been found that in fact the welds are not as satisfactory as would normally be desirable. Thus, by reducing the magnitude of the emissive agents required, the criticalness of the distribution is reduced and the cost of manufacturing electrodes is not only reduced by the amount of reduced emissive agents employed but further by the additional cost requirements attendant providing accurate emissive agent distribution within the electrode.

The present invention thus provides a highly improved welding circuit which is of substantial significance in employing a combination of different elements for providing improved current sources. Thus, the present invention provides a new improved surge source which provides a uniquely optimum operation when combined with an electrode having a low amount of emissivity material therein and an inductance providing a very minimal shift of the arc supply voltage with respect to the current. Further, the circuit is a relatively simple and inexpensive circuit which can be readily mass produced and incorporated into a welding transformer without unduly increasing the initial cost or the subsequent maintenance and by employing solid state control elements which will have an exceptionally long, reliable life.

Various modes of carrying out the invention are contemplated as being within the scope of the following claims particularly pointing out and distinctly claiming the subject matter which is regarded as the invention.

I claim:

1. An arc current supply system for establishing and maintaining an alternating current arc, comprising

an arc power transformer to provide an alternating current to an arc at a selected voltage,

power lines connected to the transformer and adapted to be connected to arc terminals for supplying alternating current to an arc,

a pair of surge stabilizing circuits each of which includes a pulse capacitor in series with a solid state switching means to control discharge of said pulse capacitor to the arc, said surge stabilizing circuits each connected in series with the arc and in parallel with the arc power transformer, each of said surge

stabilizing circuits being adapted to conduct a pulse of high voltage current to the arc during the beginning period of each successive half cycle of alternating current supplied by said arc power transformer to said arc to facilitate arc reignition during welding,
means to charge said capacitors with opposite polarities, each capacitor being charged during the half cycle the opposite capacitor is being discharged at, and
timing means forming a part of the stabilizing circuits to successively discharge said capacitors through the arc to provide an instantaneous high voltage current pulse to stabilize the arc during the corresponding half cycle, said timing means including capacitive type firing means.

2. The arc system of claim 1 having,
a reactance means serially connected in one of the power lines, and
means to supply an emissive material to the arc.

3. An arc system comprising,
a pulse single phase arc supply transformer having a primary and a secondary,
arc power lines connected to the secondary and adapted to be connected to arc terminals for supplying single phase alternating current to an arc,
a pair of surge stabilizing circuits each of which includes a capacitor in series with a triggered switching means having a firing electrode, said surge stabilizing circuits being connected in parallel with the arc supply transformer and in series with the arc during periods of conduction,
trigger means connected to the firing electrode to discharge said pulse capacitors through the arc at the initial portion of each half cycle of arc current, during arc welding to facilitate arc reiginition at the commencement of each half cycle,
charging means having an input means connected to at least a portion of the primary and an output means connected to alternately and sequentially charge said pulse capacitors with opposite polarities, each pulse capacitor being charged during the half cycle that the opposite pulse capacitor is being discharged through the arc.

4. An arc welding system comprising,
a single phase arc welding transformer having a primary and a secondary,
welding power lines connected to the secondary and adapted to be connected to welding terminals for suppling alternating current to an arc,
a pair of surge stabilizing circuits connected between the power lines and each of which includes a pulse capacitor in series with a switching means, said switching means to control discharge of said pulse capacitor to the arc,
a reactor connected in series with a power line between the secondary and the stabilizing circuits,
means to discharge said capacitors at the initial portion of the half cycles of welding current to aid the corresponding half cycle, and
means connected in parallel with at least a portion of the primary to charge said capacitors with opposite polarities, each capacitor being charged during the half cycle that the opposite capacitor is being discharged at.

5. A power system for establishing and maintaining an A.C. arc, comprising
a transformer having a primary defining power input terminals and a secondary defining a pair of output terminal means,
a pair of silicon controlled rectifiers each connected in parallel with said transformer and in series with the arc and said terminal means during periods of conduction,
a pair of pulse capacitors each connected in series with one of the rectifiers,
charging means connected to the input terminals and

to each of the said pulse capacitors to charge the respective capacitors successively during successive alternate half cycles, and
capacitor timing means connected to the output terminals and charged thereby and connected to the silicon controlled rectifier to alternately fire said rectifiers and thereby enable sequential periodic discharge of said pulse capacitors during the initiation of each successive half cycle of welding current to assist arc reignition.

6. A power system for establishing and maintaining an A.C. arc, comprising
a transformer having a primary defining power input terminals and a secondary defining a pair of output terminal means,
a reactor connected in series with the secondary between the output terminal means,
a pair of oppositely connected stabilizing circuits, each connected in parallel with said transformer and in series with the arc during their respective periods of conduction, and each including a silicon controlled rectifier having a gate, said rectifiers each being connected in series with a pulse capacitor,
said rectifiers being oppositely polarized with respect to the terminal means,
charging means connected to the input terminals and to each pulse capacitor to charge the respective pulse capacitor during successive alternate half cycles to a polarity to bias the corresponding silicon controlled rectifier to conduct, when conditioned to conduct by the respective gate,
capacitor timing means connected to the output terminal means and connected to the respective gates of said silicon controlled rectifiers to alternately fire the rectifiers in timed relation with the initial portion of the corresponding half cycle of the arc current.

7. An alternating current welding system comprising
a power transformer for supplying an alternating current to an arc, said transformer having a primary and a secondary,
a pair of welding lines including a welding electrode and a workpiece connected in series with said secondary,
a pair of surge circuits each connected in parallel with said transformer and in series with the arc during periods of conduction, each surge circuit including a gate controlled rectifier connected in series with a surge capacitor and in series with said electrodes, said rectifiers being oppositely polarized to conduct during opposite half cycles of the alternating current from said secondary, and each having a control gate to fire the rectifier into conduction,
a pair of related charging circuits connected one each to said surge capacitors and each including a diode polarized to charge said capacitors to discharge through the related silicon controlled rectifiers,
a pair of rectifier firing circuits one for each of said rectifiers, each of the firing circuits comprising a triggered switch means to control the related rectifier and a timing capacitor connected to control the switch means to cause discharge of the respective pulse capacitors through said electrode during successive half cycles of said alternating current.

8. The system of claim 7 wherein each firing circuit includes a unijunction transistor as the switch means connected with a timing capacitor in a timing circuit to the welding lines for charging of said timing capacitor.

9. The system of claim 7 having a holding capacitor paralleled with the unijunction transistor.

10. An alternating current welding system, comprising
a power transformer supplying an alternating current to an arc, said transformer having a primary, a secondary,
and main power lines, a welding circuit serially con-

nected by said main power lines to the secondary of said power transformer, said welding circuit including an electrode and a workpiece,

a pair of surge circuits each connected in parallel with said power transformer and in series with said electrode during periods of conduction, said surge circuits each including a silicon controlled rectifier connected in series with a surge capacitor and said electrode, said rectifiers being oppositely polarized to conduct during opposite half cycles of the alternating current from said secondary, and thereby cause said surge capacitors to discharge during successive half cycles of said alternating current, each rectifier having a control gate to fire the rectifier into conduction,

a surge transformer having a single primary connected across one half of the primary of the power transformer and having a pair of secondaries, said secondaries each being connected in parallel with the corresponding surge capacitor, and in series with the corresponding rectifier,

a pair of alternately and sequentially operable charging circuits one for each of said surge capacitors, and

a pair of rectifier firing circuits one for each of said rectifiers, each of the firing circuits comprising a unijunction transistor having main power terminals connected between the electrode and the workpiece, said firing circuits each including biasing resistors and a timing capacitor connected in series with an adjustable resistor across the main power lines with the unijunction transistor having a trigger terminal connected to the junction of the capacitor and the adjustable resistor, each of said firing circuits further including a holding capacitor connected in parallel with the unijunction transistor to delay the firing of said unijunction transistor so that the surge capacitors discharge through said arc sequentially during the initial portion of the successive half cycles of welding current to aid in arc reignition each half cycle and thereby stabilize the arc.

11. An alternating current welding system, comprising

an alternating current power transformer having a power primary and a power secondary,

an electrode and a workpiece serially connected to the secondary of said power transformer,

a pair of surge circuits each including a silicon controlled rectifier connected in series with a surge capacitor across the welding lines, said rectifiers being oppositely polarized to conduct during opposite half

cycles of the alternating current from said secondary, and each having a control gate to fire the rectifier into conduction,

a reactor connected in series between the secondary and the surge circuits,

a surge transformer having a single surge primary connected across one half of the power primary of the power transformer and having a pair of surge secondaries,

a pair of related charging circuits connected one each in parallel with its associated surge capacitor, each charging circuit including one of said secondaries of the surge transformer connected in series with a diode and a current limiting resistor, each diode being polarized to charge its associated capacitor to discharge through the related silicon controlled rectifiers, and through the electrode to said workpiece, and

a pair of rectifier firing circuits one for each of said rectifiers, each of the firing circuits comprising a unijunction transistor having a firing terminal and having main power terminals connected across the welding lines with biasing resistors, said circuits each including a timing capacitor connected in series with an adjustable resistor across the main power terminals of the unijunction transistor and having the trigger terminal connected to the junction of the capacitor and the adjustable resistor, each of said firing circuits further including a holding capacitor connected in parallel with the unijunction transistor to delay the firing of said unijunction transistor whereby said surge capacitors are sequentially first charged and then subsequently discharged through the electrode to said workpiece during successive half cycles of alternating current flow.

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