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(71) Applicant
North American Philips Corporation
100 East 42nd Street
New York 10017
New York
United States of America
(72) Inventors
Kenneth Frederick Lickel
Roger Stonebank
(74) Agents
R J Boxall

(54) Suppressing voltage transients in high voltage power supplies

(57) A high voltage power supply for an X-ray tube includes voltage adjusting means (10), a high voltage transformer (12), switch means (S1) connected to make and interrupt the primary current of the transformer, and over-voltage suppression means to suppress the voltage transient produced when the current is switched on. In order to reduce the power losses in the suppression means, an impedance (Z) is connected in the transformer primary circuit on operation of the switch means and is subsequently short-circuited by a switch (S2) controlled by a timer (16) after a period which is automatically adjusted to the duration of the transient overvoltage.

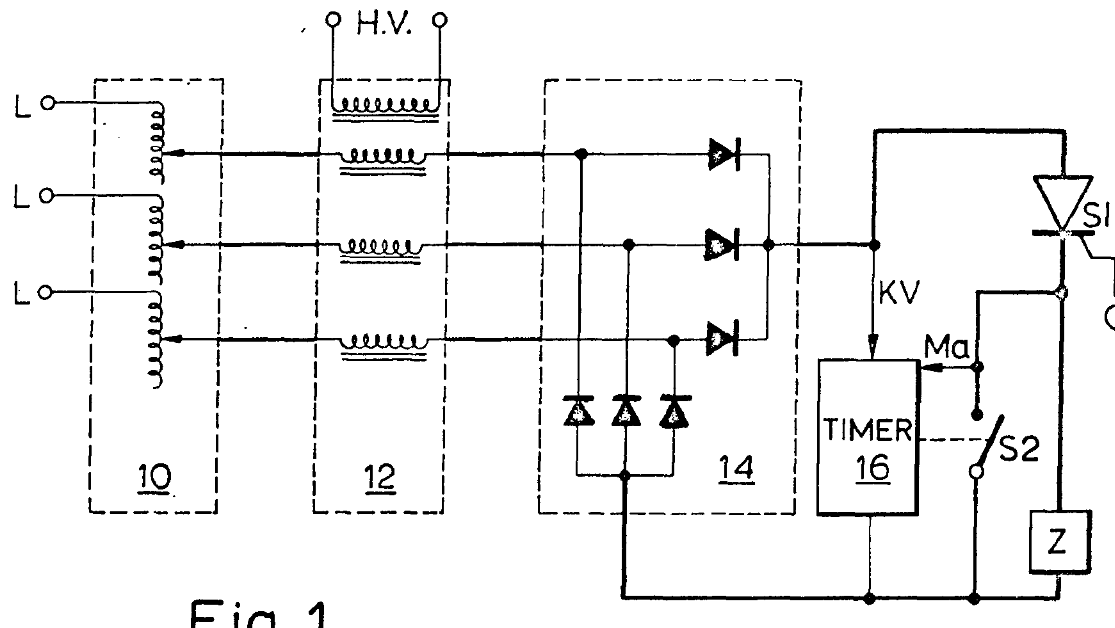

Fig.1

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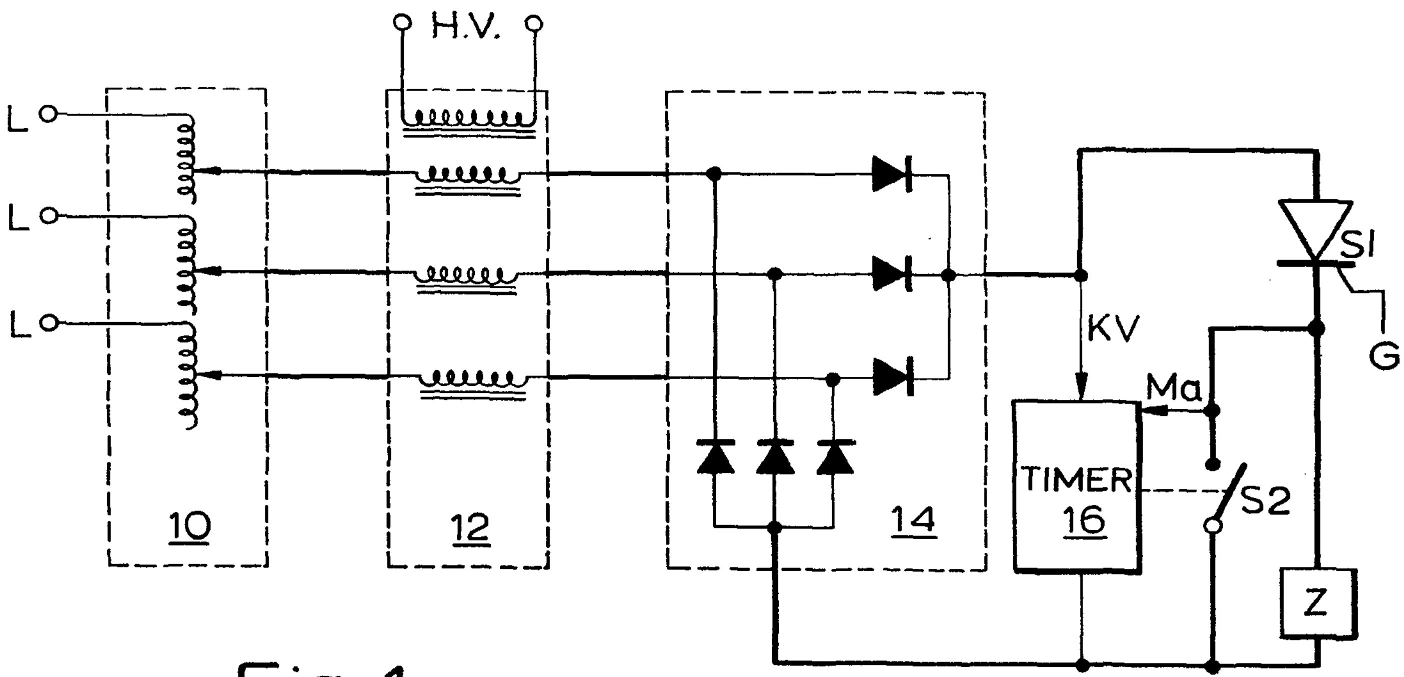

Fig.1

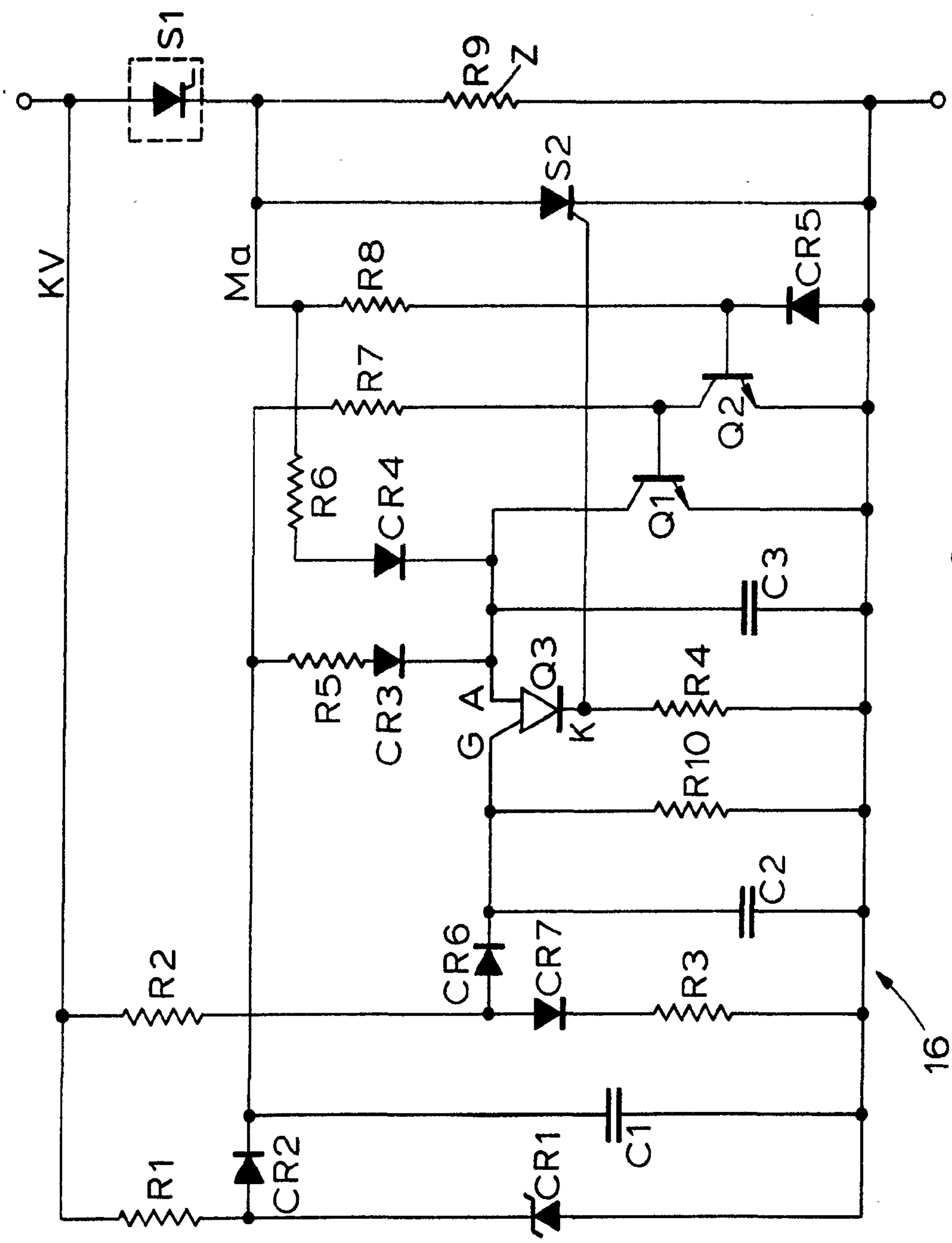
S1
R9
Z
S2
KV
Ma
R8
CR5
R7
Q2
R6
CR4
Q1
C3
R5
CR3
G
A
Q3
K
R4
R10
C2
CR6
R2
CR7
R3
CR2
CR1
C1
R1
16

Fig. 2

SPECIFICATION

High voltage power supply circuits

This invention relates to a high voltage power supply circuit comprising a high voltage supply transformer, voltage adjusting means connected between the primary of said supply transformer and terminals for connecting to a power line source, and first switch means connected to make and interrupt current flow from said source through the primary of said transformer.

High voltage supply circuits of the type defined above are used, inter alia, as high voltage generators for X-ray tube power supplies.

High voltage generators for X-ray tube power supplies may comprise a multi-phase high voltage transformer which provides power for application to an X-ray tube cathode and anode. In typical prior art circuits an AC voltage adjusting device, for example an auto-transformer, supplies line power to the multi-phase of a high voltage transformer. A switching device, for example a silicon controlled rectifier (SCR) in conjunction with a bridge rectifier, opens and closes the star point of the multi-phase primary to turn on and turn off high voltage at the X-ray tube. Inductive and capacitive effects in the transformer and associated power supply components generally cause the high voltage to rise above its steady-state level during a period immediately following completion of the circuit. The severity of this overshoot is known to increase with increasing X-ray tube voltage and to decrease with increasing X-ray tube current.

Turn-on voltage overshoot in prior art X-ray generator circuits has been suppressed by the use of damping resistors. The use of such resistors is expensive both in terms of equipment cost and power consumption. Furthermore, the specific values of damping resistors used in a given X-ray generator must be tailored to the circuit parameters of that particular generator so that separate design and circuit production is required for each distinct generator circuit. The addition of overshoot suppressing components to existing X-ray generators has, additionally, generally required the use of separate additional power supply circuits, to operate active components in the overshoot suppression circuit, and control lines to supply preset voltage and current information to the suppression delay timer.

It is, therefore, an object of this invention to provide improved circuit means for suppressing turn-on voltage transients in high voltage power supply circuits.

Another object of this invention is to provide a transient suppression circuit for high voltage power supplies which may be added to existing power supply units without the addition of further voltage and current sensing means.

In accordance with one aspect of the invention, there is provided a high voltage power supply circuit of the type defined above characterised in that it further comprises an impedance connected in series with said first switch means, second switch means connected in parallel with said impedance, and control means connected to operate said second switch means which function to assure that said second switch means are open as said first switch means are closed whereby said impedance is connected in series with the said first switch means and to close said second switch means after a computed time delay following the closing of said first switch means whereby said series impedance is removed from said circuit, said delay being computed as a function directly proportional to the voltage applied to said primary and inversely proportional to the current flow through said primary. This circuit according to the invention has the advantage that a transient-suppressing impedance is switched into the circuit only for a period sufficient to suppress the transient, the period being automatically adjusted to the transient period.

According to a further aspect of the invention, there is provided a circuit module for suppressing turn-on voltage overshoot in high power supplies of the type wherein a first switch closes to complete a current path through the primary of a high voltage transformer, the module comprising a series impedance for connection in series with said first switch; a second switch connected to shunt said series impedance; timing means connected to close said second switch as the voltage on a capacitor reaches a programmed threshold voltage; means for programming said threshold voltage in proportion to the peak voltage developed across the series combination of said first switch and said series impedance; and means for charging said capacitor as a rate proportional to the voltage developed across said series impedance. Such a module has the advantage that it can be supplied as a kit for adding to existing high voltage power supplies to provide transient suppression.

Typically, the series impedance is a resistance which is approximately equal to one half the effective system impedance in the transformer primary circuit.

An embodiment of the invention will now be described, by way of example, with reference to the accompanying drawing, of which:—

Figure 1 is a circuit diagram of a high voltage power supply in accordance with the invention, and

Figure 2 is a circuit diagram of a transient suppression timer which is exclusively connected to the high voltage transformer primary.

Fig. 1 is a power supply circuit for the high voltage circuit in an X-ray generator. In accordance with the prior art, line power from three phase line teminals L is supplied to voltage adjusting means, for example a three phase autotransformer 10, which allows adjustment of the generator high voltage level. The output of the autotransformer is connected to the three phase primary windings of a power supply high voltage transformer 12. The high voltage transformer 12 provides an output via the high voltage winding terminals H.V., (which may be a single or multi-phase high voltage secondary winding), which output is rectified, filtered and supplied to the X-ray tube in accordance with known circuit configurations of the prior art. The input of a multiphase bridge rectifier circuit 14 is connected in series with the three phase primary winding of the transformer 12. A switching element S1, typically a silicon controlled rectifier, is connected in series with the direct current output of the bridge rectifier 14. Switching-on of the silicon controlled rectifier S1 via the gate circuit G completes the primary star point connection of the high voltage transformer 12 and thus permits current flow in the primary and secondary circuits. The foregoing circuit description is typical of prior art X-ray high voltage generators.

In accordance with a feature of the present invention, a series impedance Z is connected in series with the silicon controlled rectifier S1. Second switch means S2 are connected in shunt with the impedance Z so that the impedance Z is included in the circuit when the second switch means S2 are open and is effectively removed from the circuit (by being short-circuited) when the second switch means S2 are closed. The switch means S2 are controlled by a timer circuit 16 which functions to open the switch means S2 when current flow is blocked through the silicon control rectifier S1 and to close the switch means S2 after a computed time delay following the turn on of the SCR S1. The impedance Z is thus inserted in series with the transformer primary circuit for a time interval during which the most severe turn-on transient overshoot effects occur and is removed from the transformer primary circuit after those transient effects subside and steady-state circuit conditions are reached. The time delay produced by the timer circuit 16 is determined, in a manner more specifically described below with reference to Fig. 2, by a computer circuit which controls the time delay in direct proportion to the voltage produced by the autotransformer 10 and applied to the transformer primary windings (as sensed at the output of the bridge rectifier on line KV) and in inverse proportion to current flow in the transformer primary circuit (as sensed across the impedance Z on line Ma).

A transient suppression circuit which comprises the timer the secondary switch S2 and the impedance Z may be added to existing prior art high voltage generator circuits in modular kit form. A specific embodiment of the circuit described with reference to Fig. 2 derives its entire power supply from the lines KV and Ma and thus does not require auxiliary power supply circuits for operation of the timer 16 or the switch S2. This embodiment comprises a programmable unijunction transistor and is powered directly from the transformer primary circuit via the line KV.

Power from the anode of the SCR S1 is transmitted through line KV to a regulated power supply comprising dropping resistor R1, zener diode CR1 and rectifier CR2 in conjunction with filter capacitor C1. Regulated voltage thus derived is supplied to the anode of a unijunction transistor Q3 through a resistor R5 and rectifier CR3 and is supplied to the collector of an amplifier transistor Q2 through a resistor R7.

The voltage on line KV is divided and peak detected in a circuit consisting of resistors R2 and R3,,rectifiers CR6 and CR7, capacitor C2 and resistor R10 and is then applied to the gate 6 of the programmable unijunction transistor Q3 to control its threshold voltage. A signal proportional to the transformer primary current is derived across the impedance Z on line Ma and utilized to charge capacitor C4 through resistor R6 and rectifier CR4. When the voltage on capacitor C3, at the anode A of the programmable unijunction transistor Q3, exceeds the unijunction transistor gate voltage the equivalent anode to cathode resistance of the unijunction transistor abruptly drops and the pulse thus produced across the resistor R4 at the cathode K of transistor Q3, and hence on the gate of the silicon controlled rectifier S2, forces the silicon controlled rectifier S2 into conduction, shunting the impedance Z and effectively removing it from the circuit. Voltage on line Ma also causes current flow into the base of transistor Q2 through resistor R8 which biases transistor Q1 in an off condition. When SCR conducts, transistor Q2 is turned off; turning on transistor Q1 and discharging capacitor C3 to return the circuit to its original condition. The time delay between the turn-on of SCR S1 and the turn-on of SCR S2 thus increases in direct proportion to the voltage on line KV, which is proportional to the transformer primary voltage, and in inverse proportion to the voltage at line Ma, which is proportional to the transformer primary current. The circuit of Fig. 2 thus functions to insert the overshoot limiting impedance Z, in the form of a resistor R9, for an optimum time to suppress the overshoot with minimum excess power dissipation or circuit disturbance.

As an example and to enable others to more easily practice the invention; in a typical circuit for use with a model MM100C X-ray generator manufactured by Philips Medical Systems Incorporated of Helton, Connecticut and having a power output from 40 to 150 Kilivolts and from 10 milliamps to 1,200 milliamps derived from three phase 440 volt power lines; the values of circuit components in Fig. 2 are as follows:

R1	35 Kohm	50 watt
R2	820 Kohm	2 watt
R3	22.1 Kohm	$\frac{1}{2}$ watt
R4	4.7 Kohm	$\frac{1}{2}$ watt
R5	82.5 Kohm	$\frac{1}{2}$ watt
R6	100 Kohm	2 watt
R7	68 Kohm	$\frac{1}{2}$ watt
R8	10 Kohm	2 watt
R9(Z)	0.375 Kohm	50 watt
R10	200 Kohm	$\frac{1}{2}$ watt

C1	10μF in parallel with 100pF
C2	0.1 μF
C3	0.1 μF
CR1	20 volt zener diode
Q3	Unijunction transistor type 2N6027 (Motorola).

The delay times produced by the circuit vary from approximately 1 millisecond to approximately 2 milliseconds depending on the values of primary voltage and current. The value of resistor R9 was chosen to be approximately one half of the mains power supply impedance reflected in the primary of transformer 12.

The circuit of the present invention allows transient voltage suppression in X-ray generator circuits and allows installation as a separate modular kit without separate external power supply and signal connections.

CLAIMS

1. A high voltage power supply circuit comprising a high voltage supply transformer, voltage adjusting means connected between the primary of said supply transformer and terminals for connecting to a power line source and first switch means connected to make and interrupt current flow from said source through the primary of said transformer; characterised in that the circuit further comprises an impedance connected in series with said first switch means; second switch means connected in parallel with said impedance; and control means connected to operate said second switch means which function to assure that said second switch means are open as said first switch means are closed whereby said impedance is connected in series with said first switch means and to close said second switch means after a computed time delay following the closing of said first switch means whereby said series impedance is effectively removed from said circuit, said time delay being computed as a function directly proportional to the voltage applied to said primary and inversely proportional to the current flow through said primary.

2. A circuit a s claimed in Claim 1, wherein said second switch means is a semiconductor switch.

3. A circuit as claimed in Claim 2, wherein said control means comprise a unijunction transistor connected to fire said semiconductor switch; integrating means connected to integrate the voltage developed across said series impedance and to apply said integrated voltage to the anode of said unijunction transistor; means to detect the voltage developed across the series combination of said first switch means and said impedance and to apply a signal derived therefrom to the gate of said unijunction transistor; and means to discharge said integrating means when said second switch means is conducting.

4. A circuit as claimed in Claim 3, wherein the power source for said control means is derived from voltage developed across the series combination of said first switch means and said series impedance.

5. A circuit as claimed in Claim 1, wherein the value of said series impedance is approximately equal to one half of the power supply impedance which is reflected in said primary of said transformer.

6. A circuit module for suppressing turn-on voltage overshoot in high voltage power supplies of the type wherein a first switch closes to complete a current path through the primary of a high voltage transformer, the module comprising a series impedance for connection in series with said first switch; a second switch connected to shunt said series impedance; timing means connected to close said second switch as the voltage on a capacitor reaches a programmed threshold voltage; means for programming said threshold voltage in proportion to the peak voltage developed across the series combination of said first switch and said series impedance; and means for charging said capacitor at a rate proportional to the voltage developed across said series impedance.

7. A high voltage power supply substantially as herein described with reference to the accompanying drawings.

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