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TRIAC/SCR PROPORTIONAL CONTROL CIRCUIT

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CONTROL CIRCUIT

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TRIAC/SCR PROPORTIONAL CONTROL CIRCUIT

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5 States Government has rights in this invention and title thereto is in the Department of Energy.

Background of the Invention

This invention relates to power controllers, specifically those for use in controlling the power

10 applied to heating elements used in annealing of very large metal objects. In particular this invention is useful in the annealing of installed and irradiated nuclear reactor pressure vessels. More particularly, this invention relates to power controller devices which

15 provide high resolution linear power adjustment of the power applied, thereby obviating the need for measurement of power delivered to the load by the power controller for control purposes. The load may be a heating element, for example.

20 Many types of power controller devices are known in the prior art. The simplest power controller, known for a century or more, uses a rheostat or a

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variable ratio transformer to control the delivered

power. For simple annealing, such as small glass kilns,

such devices suffice. This approach suffers the

disadvantage, however, of having non-linear control.

5 That is, the "operator" controls current or more usually

voltage approximately linearly, but the power delivered

is proportional to the square of the varied quantity, so

that the control (i.e., the responsiveness of the power

delivered to changes in current or voltage) is inherently

10 quadratic, not linear. Sophisticated annealing tasks,

such as the annealing of nuclear reactor pressure

vessels, require the accuracy of linear control, i.e., a

linear variation in the power delivered in response to an

operator-controlled change in current or voltage.

15   The standard approach to achieving linear power

control has been to use systems which turn the power on

for a portion of a fixed duty cycle, typically one or two

seconds. Although the delivered power is quadratic in

response to changes in the current or voltage, the

20 amplitude of the AC current of the delivered power is

approximately constant over the duty cycle, and hence the

average power delivered over the duty cycle is linear

with the proportion of time the delivered power is "on."

The response time of the change in temperature of heating

25 elements and the heated object to be annealed are such

that time-varying power levels by turning the current on

and off over one or two seconds has negligible effect on the temperature achieved.

Unfortunately, however, there are practical problems in using conventional systems to control heating

5   elements used in sophisticated annealing such as that of nuclear reactor pressure vessels. The prior art linear power controller, which has been in use until the present invention, produces large step increases in power, especially at low percentages of delivered power, in

10   reponse to changes in the controller settings, even with linear input control, because it can only add or subtract an integral cycle of the 60 Hertz (Hz) power signal, thereby producing highly discontinuous changes in delivered power level.

15   Increasing the length of the duty cycle helps but does not fundamentally alleviate the problem. Measurement of power delivered to the object to be annealed is therefore required to assure that actual power levels obtained are known to an acceptable

20   accuracy.

In prior art designs using the above-described standard approach, 60 Hz power to the load is controlled using an on or off system with a fixed duty cycle such that integral numbers of complete 60 Hz sine cycles

25   (synchronized to the line frequency) are applied to the load during the "on" portion of the controller duty cycle

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and no power is delivered during the "off" portion. For example, as illustrated in Figure 1, at an input command of 10% power with a one second duty cycle, the controller should output to the load six complete 60 Hz cycles of power (0.1 second) every 60 cycles (1.0 second). Consequently, at low percentages of maximum deliverable power there is a significant time during which no power is applied to the load (e.g., 54 cycles at 10% power).

As described above, a problem inherent in this type of control is that large relative changes in power delivered are inherent at low absolute levels of power because the current can only change by an integral number of cycles. The control is thus grossly discontinuous in this region of operation. This problem can be referred to as granularity of control.

For example, an increase in power using this type of controller from six cycles or 10% power to seven cycles or 16% power is actually a relative change of 17% (one cycle out of six) in power being delivered. At 50% power (see Fig. 1), the load waveform for a duty cycle of one second supplies power for 30 cycles and is then off for 30 cycles. Specialty applications such as nuclear reactor annealing require not only the linearity of control offered by duty cycle systems but also precision of change of power level of one in a thousand, i.e., a resolution of 0.1% in relation to the 100% power level.

With conventional controllers it has been necessary to measure load power due to the uncertainty at this level, especially at low power percentages. The added instrumentation required for feedback from the

5   measurement of delivered power adds complexity and expense to the power controller apparatus. These measurements are also complicated due to the burst or discontinuous nature of the applied waveform.

Some improvement in resolution at low duty

10   cycles can be achieved by increasing the total length of the duty cycle, e.g., to two seconds. In this case, a 20% power level is provided by 12 cycles out of 120 cycles; the next step increase in power is to 13 cycles or approximately 10.8% power and therefore a change of

15   only about 8% (one cycle out of 12). Although improved, this technique still has significant granularity and still requires measurement of load power for accuracy of control.

Thus there is a need for a simple and

20   convenient power controller providing both linearity and high resolution in power control for meeting annealing specifications. In particular, reactor vessel annealing requires a well controlled, slowly changing, uniform heat distribution to preclude thermal stresses. The accuracy

25   and the resolution of control of input power directly affects the uniformity of temperature which in turn

directly controls the likelihood of a successful

annealing. Uniformity is accomplished with multiple

heater banks comprising a sufficient number of well

controlled electrical heating elements. Step changes in

5   electrical power input, and thus heat input, disrupt both

the uniformity and the slow rate of change, potentially

causing damaging thermal stresses.

In addition, the annealing of particular

interest is for an installed, previously operated nuclear

10   reactor vessel. Installed shielding materials are

subject to heat damage at temperatures only slightly

above minimum annealing temperatures. The margin between

acceptable minimum annealing temperatures and maximum

safe temperatures for these materials is very narrow. It

15   is therefore extremely important that vessel temperature

uniformity, and thus control of electrical input to the

heating elements, be as precise as is practical to assure

that the entire vessel has reached the necessary

annealing temperature but also stays below maximum

20   temperature constraints.

Two other factors which affect the degree of

temperature control and uniformity are variations in line

voltage and the tendency of heating elements to increase

resistance with increasing temperature. It would be

25   useful to be able to feed back to the control system for

adjustment of the input control voltage a signal based on

changes in the amplitude of the line voltage and another

signal based on the temperature of the heating element to

maintain stability and control. The granularity of the

prior art control system makes use of such signals for

5   fine control problematic.

When feedback signals are used, random noise in

the input channel potentially subjects the system to a

well known problem with feedback loops, oscillation.

Thus there is also a need in systems using feedback

10   signals to be able to minimize susceptibility to input

noise. The current invention answers all of these needs.

Summary of the Invention

The present invention provides a stepless,

linear, high resolution power control circuit for

15   controlling AC power applied to a load, said power

control circuit comprising (1) a converter for converting

an analog input voltage to a first output pulse signal

with a frequency linearly related to the input voltage,

said converter being capable of providing a predetermined

20   output pulse signal width; (2) a detector for generating

a 60 Hertz or 120 Hertz zero crossing second output pulse

signal syncronous with an AC input signal synchronized

with the said load power voltage and having a second

predetermined-output pulse width; and (3) a flip-flop

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for activating a monostable multivibrator, the reset
input of said flip-flop being coupled to said converter
and responsive to said first pulse signal, and the set
input of said flip-flop being coupled to said detector
5   and responsive to said second pulse signal.

Because of the combination of linearity and high
resolution of the present invention, straightforward
feedback techniques for line power, temperature, and
other variables which affect uniformity, are possible.
10 Inherent noise immunity of the voltage to frequency
conversion used in the present invention eliminates the
requirements for current loop control, thereby permitting
simpler control signals. In addition, the system can
utilize a voltage to frequency converter with a large
15 multiple of 60 Hz base frequency with frequency dividers
to reduce the control pulses to the range 0 to 60 Hz.
This approach vastly reduces the impact of any input
noise.

An object of the invention is to provide a
20 power controller which, by virtue of its high resolution,
linearity, and accuracy, eliminates the need to measure
power output in such an apparatus.

A further object of this invention is to
provide a power controller having a reduced number of
25 components and a lower cost of production by eliminating
the need to measure load power.

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Still other objects, features, and advantages of the present invention will become readily apparent to those skilled in this art from the following description of a presently preferred embodiment of this invention.

5 As previously indicated, the invention will be set forth in part in the description that follows and in part will become apparent to those skilled in the art upon examination of the following or may be learned with the practice of the invention by means of the

10 instrumentalities and combinations particularly pointed out in the appended claims. Accordingly, the following description and attached drawings are illustrative and not restrictive.

15 Brief Description of the Drawings

The accompanying drawings, incorporated in and forming a part of the specification, illustrate several aspects of the present invention and, together with the written description, serve to further explain the

20 principles of the invention.

Fig. 1 is a timing diagram for the conventional prior art power controllers at 10%, 11.7% and 50% power, respectively.

Fig. 2 is a schematic diagram of a power controller

25 in accordance with a first embodiment of the present invention.

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Fig. 3 is a timing diagram of a power controller according to the invention operating at slightly less than 10% power.

Fig. 4 is a timing diagram of a power controller according to the invention operating at slightly less than 50% power.

Fig. 5 is a half wave timing diagram of a power controller according to the invention operating at slightly less than 10% power.

Fig. 6 is a schematic diagram of a power controller in accordance with a second embodiment of the present invention.

Fig. 7 is a schematic diagram of a power controller in accordance with a third embodiment of the present invention.

Fig. 8 is a schematic diagram of a power controller in accordance with a fourth embodiment of the present invention.

Fig. 9 is a schematic diagram of a power controller in accordance with a fifth embodiment of the present invention.

Detailed Description of the Invention

The present invention provides many advantages over conventional techniques. This invention provides

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continuous duty cycle power control function without significant step increases in power. Moreover, the present invention can be designed for high immunity to control signal noise. The invention is easily adaptable

5   to controlling output based on a variety of input or feedback signals returned to the analog input. Further, all analog circuits can be isolated from the power circuits through optical or transformer coupling of the V-F output. The remainder of the circuit can be included

10   in the SCR/TRIAC control module. Still further, the present invention provides control resolution of at least three orders of magnitude, and further improvements can be made using V-F converters now in existence which are capable of spanning seven orders of magnitude. Finally,

15   this invention comprises a simple circuit with a low parts count and hence is reliable and easy to manufacture.

To achieve the foregoing and other objects, the present invention uses a control circuit with a frequency

20   output proportional to an input voltage or current to vary the duty cycle of a silicon controlled rectifier (SCR) or a three terminal AC controller (TRIAC) which provides pulses of power to the load as determined by the input voltage or current. A silicon controlled rectifier

25   is a solid state diode device which only conducts in one direction and only when its control electrode is biased

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with a certain control voltage. A TRIAC is a solid state device which conducts in both directions but only when its third electrode is biased with a certain control voltage.

5   In particular, the current invention achieves improved power control by proportionally and finely controlling the AC power applied to the load with pulses synchronous to the AC line voltage through a TRIAC or SCR. The invention achieves these results by means of a

10   control circuit comprising: a converter which converts an analog input voltage linearly to a pulsed output with a fundamental frequency proportional to the input voltage such that the output pulses have a narrow predetermined pulse width; a zero crossing detector which generates a

15   60 Hertz or 120 Hertz narrow pulse signal synchronized with the AC power voltage; a flip flop circuit which triggers a monostable multivibrator, with the V-F converter controlling the "reset" input of said flip flop, and the zero crossing detector controlling the

20   "set" input of said flip flop, such that only after both signals have arrived will the flip flop activate the SCR or TRIAC; and a logic gate for assuring that the monostable multivibrator is controlled by the flip flop to preclude the rare instance where the set and reset

25   condition are in coincidence.

          Referring to the drawings, as previously

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indicated, Fig. 1 illustrates the granularity of the power delivered by the prior art controller. Fig. 2 schematically shows a presently preferred embodiment of the power controller device of this invention. This

5   simplest embodiment of the invention comprises a voltage to frequency (V-F) converter (3), a 60 Hertz zero crossing detector (6), a reset-set (R-S) flip flop circuit (4), a monostable multivibrator (8) and a TRIAC or Silicon Controlled Rectifier (SCR) power circuit (14).

10   These elements are standard electronic hardware or modules whose operating characteristics are described in electronic reference materials and/or catalogs which will be known to those skilled in the art. A + or - zero crossing (half-wave) detector can be used instead of a

15   fullwave zero crossing detector.

The invention involves the use of a linear voltage to frequency (V-F) converter (3) to produce a pulse signal which in combination with other pulse signals provides finely resolved linear AC power control. An

20   output pulse of the V-F converter (3) at a frequency which is a fraction less than one of the AC power line is required to enable the flip flop circuit to pulse the SCR or TRIAC which controls the power circuit. It does so by resetting the flip flop circuit, which then is enabled to

25   activate the SCR or TRIAC when it receives a set pulse from the zero crossing detector circuit (6). The

14

detector circuit (6) produces a pulse when it obtains a

positive going zero voltage and activates the enabled

(i.e., reset) R-S flip flop (4). The pulse from R-S flip

flop (4) activates the SCR or TRIAC power circuit (14).

5   This apparatus in effect varies the duty cycle of the

applied power continuously to achieve finely resolved

linear control, and such resolution results in the

initial application of power (1) to the load (16) at very

close to zero input voltage. Half wave power cycles can

10   alternatively be selected by using a + and - zero

crossing (halfwave) detector instead of the positive zero

crossing (fullwave) detector.

As shown in Figure 2, an analog input voltage

source (15) produces a voltage proportional to the

15   desired delivered power level which is supplied to a

voltage to frequency (V-F) converter (3). The analog

input voltage comes from a variable voltage source. The

output of the V-F converter is arranged either directly

or through a countdown circuit (12) to provide an output

20   pulse to the flip flop whose frequency varies from

slightly above zero to slightly greater than 60 Hertz

with an output pulse width on the order of 1 microsecond,

the actual pulse frequency being in direct proportion to

the analog input voltage. A 60 Hz zero crossing detector

25   circuit (6), driven by the AC signal source common to the

main AC power circuit, generates a positive going zero

15

crossing signal synchronous with the 60 Hz power signal. This detector circuit (6) also has an output pulse width on the order of 1 microsecond, which is supplied to the flip flop (4).

5   The V-F signal is arranged to drive the "reset" side of an R-S (reset-set) flip-flop (4). The 60 Hertz zero crossing signal is arranged to control the "set" side of the R-S flip flop. Each pulse from the V-F converter resets the flip flop. The next consecutive "0"

10   (zero) crossing pulse from the 60 Hertz zero crossing detector (6) sets the flip flop and triggers a 10 millisecond multivibrator "on" pulse. The SCR/TRIAC includes an interface that provides isolation and signal power amplification adequate to trigger the SCR/TRIAC.

15   Since the monostable multivibrator (8) is triggered synchronously with the positive "0" crossing of the 60 Hertz power signal and the pulse width of the output pulse of the multivibrator (8) is in excess of 8.33 milliseconds, but less than the 16.6 milliseconds, the

20   power circuit will be triggered for one complete cycle of the AC line power. The output of the V-F converter (3) is a pulse signal with frequency proportional to the linear voltage input. Because the monostable multivibrator is in the "on" condition only when the flip

25   flop and the V-F pulses are in the necessary synchronization, the delivered power is a pulse that only

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occurs once in every N cycles, where N = 100% divided by the power percentage input associated with the input voltage selected to be applied to the V-F converter. The resolution of the average delivered power is thus the

5   resolution of the V-F converter.

For example, considering the operation at 10% power, the TRIAC/SCR is triggered by the monostable multivibrator output so that one complete 60 Hertz cycle of the line power out of every 10 is applied as the

10   delivered power to the load. The V-F converter is set to produce a pulse slightly faster than every .167 seconds (6 Hz) by virtue of its design, which resets the R-S flip flop. The 60 Hz crossing detector produces a pulse every cycle, which sets the flip flop. Since the V-F resets

15   the flip flop just prior to the set by the 60 Hertz zero crossing signal, a pulse is produced out of the flip flop every 0.1 second which triggers the monostable multivibrator. This in turn fires the TRIAC or SCR device (14) for one cycle, thereby producing the desired

20   10% power applied to the load.

Figure 3 illustrates the waveforms present at locations A, B, C, D, and E of Figure 2 at slightly less than 10% power level. The operation at slightly less than 10% power illustrates how the V-F and zero crossing

25   detector signal interact with the flip flop to apply one complete 60 Hertz voltage cycle to the load approximately

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every 10 cycles. It also illustrates the shifting of the
V-F output pulse outward, which causes the output at D
and E in Figure 3 to shift and thus move out by one cycle
the applied voltage signal. This shift causes a slight
5   power reduction. At exactly 10% commanded power, one
cycle for every 10 would be applied continuously as
stated at the beginning of this paragraph.

At an analog input voltage command of 10.1%
power (a 1% change from 10%) the output of the V-F is
10   slightly greater than 6.06 Hertz. Therefore a single,
full 60 Hertz cycle of power would be applied to the load
once every 10 cycles for 9, 10-cycle intervals and then
in the 10th interval the power is applied 8 cycles later
instead of 9 cycles producing a total of 10 "on" cycles
15   for a total of 99 cycles or an average power of 10.1%.
The same analysis applies for any level of commanded
power due to the linear nature of the V-F converter.

At 50% power, every other 60 Hertz cycle is
applied to the load or the repetition rate is 30 Hertz.
20   The frequency output of the V-F is slightly greater than
30 Hertz and the crossing detector generates a R-S set
every 60 Hertz. The operation at slightly less than 50%
power level is illustrated in Figure 4. Another way of
looking at this performance is that the V-F converter
25   output frequency, which is proportionally controlled by
the commanded power signal, forces the applied power duty

18

cycle to be related to the inverse of the (V-F) output frequency (to within +/- 1 cycle to allow for zero crossing detector frequency jitter).

By comparison to the conventional power controller illustrated in Figure 1, it is obvious that the power is applied much more uniformly and regularly. At 10% and 50% power with a 1 second duty cycle, the conventional power controller applies power every second for 6 cycles and 30 cycles respectively. This leaves an off period of 54 cycles and 30 cycles respectively. The invention supplies power every 10 cycles and every other cycle for 10% and 50% power, respectively.

A second embodiment illustrated in Fig. 6 uses a half cycle power cycle by employing a two way or +/- zero crossing detector trigger signals (120 Hz) instead of only an up detector as well as a multivibrator with less than an 8 millisecond pulse. The performance of this embodiment is illustrated in Figure 5. This approach smooths the input power by a factor of two. The disadvantage to this approach is possible saturation of the power transformer powering the control circuit at frequency multiples which select consecutive positive or consecutive negative cycles.

Another embodiment is illustrated in Figure 7. In this embodiment an "AND" gate (7) and an "OR" gate (5) preclude the rare instance when both the set and reset

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are in coincidence and, in that case, trigger the monostable multivibrator directly.

Highest accuracies of control require modification of the control signal to null the effect of

5   line voltage changes. Figure 8 adds this feature by incorporating a true RMS signal (18) to appropriately modify the control signal. The accuracy of the voltage to frequency converter (3), the root means square (RMS) converter (18), and multiplier (9) should be chosen for

10   the desired accuracy of signal to power level conversion, as shown in the simplified block diagram of Fig. 8. The accuracy of the voltage to frequency converter (3) is the only component that directly effects the accuracy of signal to power level conversion. The accuracy of the

15   voltage to frequency converter (3) should be commensurate with the overall desired performance.

The features described above can be provided as a power controller, when the controller function is supplemented with a control loop, as shown in Figure 8.

20   Figure 8 includes the basic aspects of the present invention, as set forth in Figure 2, and in addition provides a signal which is inversely proportional to RMS line voltage. By using the multiplier (9), the RMS voltage (18) inversely proportional to the power line

25   voltage (1) can be used to modify the input voltage signal to correct for line voltage changes. As shown in

20

Figure 8; this function of power line voltage (nominal

line voltage would be equal to one) is multiplied with

the desired power signal through the use of an analog

multiplier (9) (i.e., Burr Brown 4214). The resulting

5   signal is passed to the V-F converter (3). As stated,

the output of the V-F converter can be arranged directly

or through a countdown circuit (12), which divides the

high frequency down to an acceptable range of 0 to

slightly greater than 60 Hertz. The control signal in

10   this configuration is proportional to power.

Analog components as shown in Figure 8 are

readily available with the following accuracies. The

Burr-Brown VFC62 voltage to frequency converter.

specification has a linearity as high as .005% maximum at

15   10 Kilohertz fullscale with scale and gain drifts on the

order of +/- 50 parts per million (ppm) of Full Scale

Reading/degrees Centigrade (FSR/deg C). Multipliers such

as the Burr-Brown AD632 are accurate to +/- 0.5% with a

temperature coefficient of 0.01% per degrees C. The

20   Burr-Brown 4341 is accurate to 0.2% +/- 2 millivolts with

a 10 volt fullscale output. These components would

contribute less than 0.1% of fullscale system

inaccuracies. Heater resistance feedback would be

required to approach this level of accuracy.

25   Other enhancements illustrated in Fig. 9 could

improve accuracy still further. The load resistance in

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most instances is a heater element (2) which will change

impedance with temperature. A heater temperature

feedback signal (17) could correct for this change to

achieve improved accuracy of the system.

5   It should also be apparent that the output

signal of the voltage to frequency converter (3) could be

provided by a microprocessor based system. Digital

manipulation of feedback (17) and power level demand

would control a counter timer which would output a

10   variable frequency signal identical to the voltage

converter signal. In other words, the digital   *w/H Aug 13, 1991*

~~manupulation~~ *manipulation* of the control and feedback signals thus

produce a digital value of the desired power cycle

repetition rate, which would then preset a counter timer

15   after each overflow. The overflow output pulse would

thus reproduce the voltage to frequency signal.

Additionally, the zero crossover to synchronize the AC

line could be input as an interrupt, which would cause an

interrogation of the register set by the counter timer

20   overflow. When the register is found set, an output

register would output a control signal to a power module.

The output register would be reset at a time commensurate

with the requirement of the applied power module. This

would be another approach which utilizes the power

25   control concept presented in this patent.

          In the case of a pressure vessel annealing,

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many individual heaters are employed to improve uniform heatup. One microprocessor could support several independently controlled heaters, while feedback signals could be shared. The counter timer preset value need not

5   be calculated on a cycle-by-cycle basis, but periodically on a time base adequate for the computer to control several counter timers and their associated heaters. Zonal vessel temperatures and line voltage monitoring signals could be shared for a complete all encompassing

10 annealing heater control system.

The proportional control circuit of the invention may further comprise pre-filtering means for derivation of voltage signals and temperature signals necessary for control.

15 Accordingly the invention provides a linear high resolution power control circuit for controlling AC power applied to a load through a three terminal AC controller or a silicon controlled rectifier, said power control circuit comprising a converter means responsive

20 to an analog input voltage to produce a first pulse signal of predetermined output pulse width and with a frequency that varies linearly with the amplitude of the input voltage; a detector means for generating a zero crossing second output pulse signal synchronous with the

25 frequency of an AC load power voltage and having a second predetermined output pulse width; and a flip flop means

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for activating a monostable multivibrator, said first

pulse signal being applied to the reset input of said

flip flop means, and said pulse signal being applied to

the set input of said flip flop means.

5   The foregoing description of the invention has

been presented for purposes of illustration and

description. It is not intended to be exhaustive or to

limit the invention to the precise form disclosed.

Obvious modifications or variations are possible in light

10 of the above teachings.

         The presently preferred embodiment described

herein illustrates the principles of the invention and

its practical application so that one of ordinary skill

in the art can utilize the invention in various

15 embodiments and with various modifications as are suited

to the particular use contemplated. Accordingly, the

scope of the invention is defined by the following

claims.

Abstract of the Disclosure

A power controller device which uses a voltage-to-frequency converter in conjunction with a zero crossing detector to linearly and proportionally control AC power being supplied to a load. The output of the voltage-to frequency converter controls the "reset" input of a R-S flip flop, while an "0" crossing detector controls the "set" input. The output of the flip flop triggers a monostable multivibrator controlling the SCR or TRIAC firing circuit connected to the load. Logic gates prevent the direct triggering of the multivibrator in the rare instance where the "reset" and "set" inputs of the flip flop are in coincidence. The control circuit can be supplemented with a control loop, providing compensation for line voltage variations.

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FIG. 1 TYPICAL CONVENTIONAL CONTROLLER AT 10% POWER
6 CYCLES ON, 54 OFF   (1 SECOND DUTY CYCLE)

ON FOR SIX CYCLES   OFF FOR 54 CYCLES

NEXT INCREMENT IN POWER   11.7 %
7 CYCLES ON, 53 OFF   (1 SECOND DUTY CYCLE)

CONVENTIONAL CONTROLLER AT 50% POWER
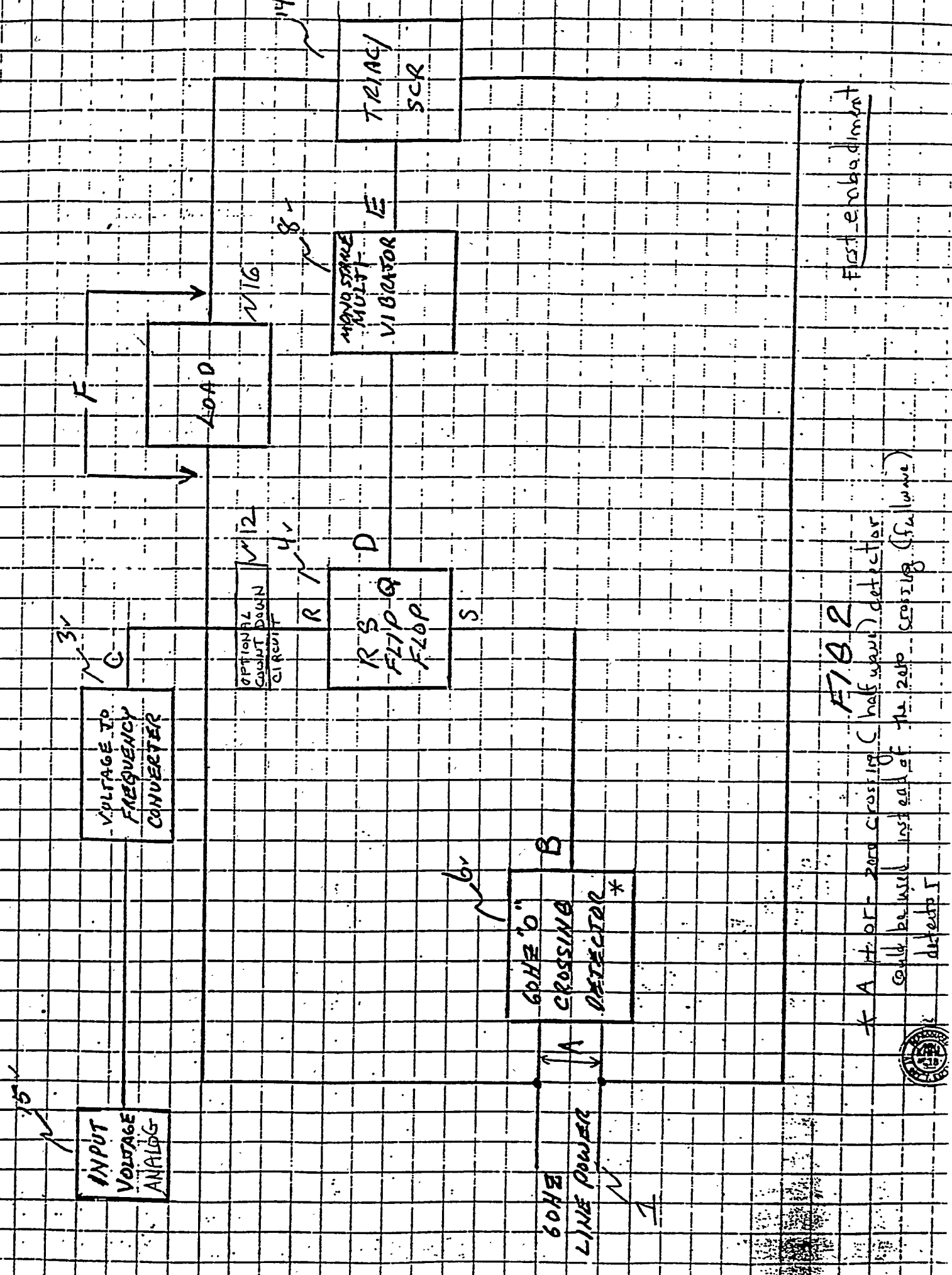30 CYCLES ON, 30 CYCLES OFF   (1 SECOND DUTY CYCLE)

ON 30 CYCLES   OFF 30 CYCLES   ON 30 CYCLES

SCR/ TRIAC POWER CONTROLLER

```
INPUT
VOLTAGE
ANALOG          5

      VOLTAGE TO
      FREQUENCY
      CONVERTER       3    G

                         OPTIONAL
                         COUNT DOWN     12
                         CIRCUIT        4
                                        R
                                                    D
                              RS          Q
                             FLIP
                             FLOP
                                        S

      60HZ "0"
      CROSSING          6
      DETECTOR *
                        B

60HZ
LINE POWER    1    A

                         F
                              LOAD        16
                                              8
                                        MONOSTABLE
                                        MULTI-           E
                                        VIBRATOR

                                                    TRIAC/
                                                    SCR          14

                                        First embodiment

* A + or - zero crossing ( half wave) detector
  could be used instead of the zero crossing (full wave)
  detector 5

FIG. 2
```
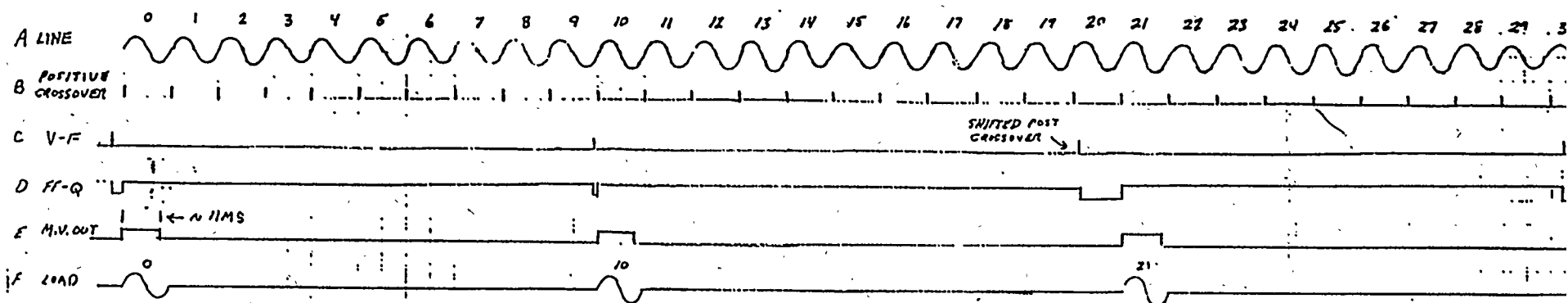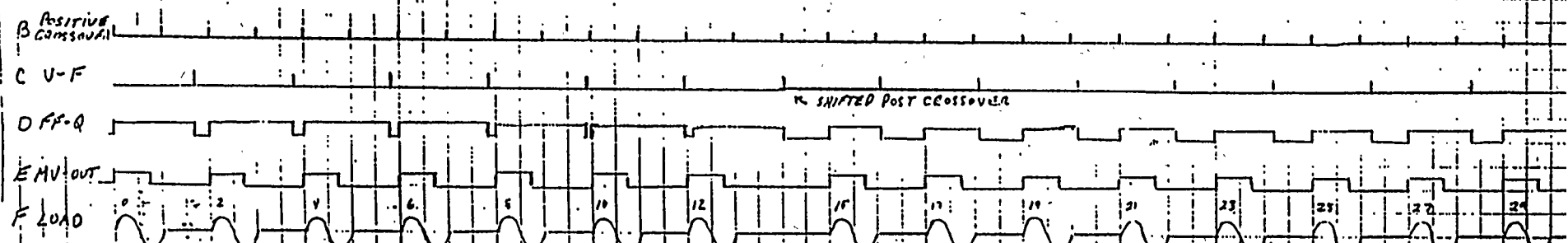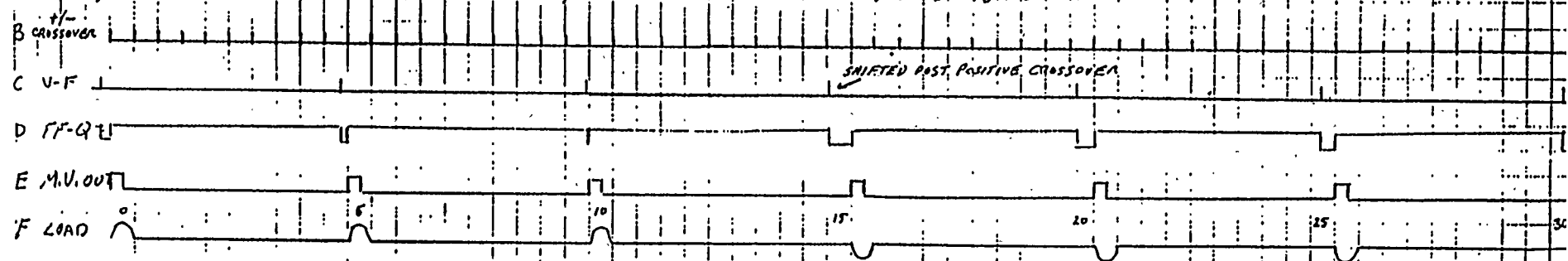
FIG 3   SLIGHTLY LESS THAN 10% POWER

A LINE
B POSITIVE CROSSOVER
C V-F   SHIFTED POST CROSSOVER
D FF-Q
E M.V. OUT   ← ~11MS
F LOAD

FIG 4   SLIGHTLY LESS THAN 50% POWER

B POSITIVE CROSSOVER
C V-F
D FF-Q   ← SHIFTED POST CROSSOVER
E MV OUT
F LOAD

FIG 5.   HALF WAVE, SLIGHTLY LESS THAN 10% POWER

B +/− CROSSOVER
C V-F   SHIFTED POST, POSITIVE CROSSOVER
D FF-Q
E M.V. OUT
F LOAD

FIGURES 3, 4, 5

SCR/TRIAC Power System Controller

INPUT VOLTAGE ANALOG — 5

VOLTAGE TO FREQUENCY CONVERTER — 3

C

OPTIONAL COUNT DOWN CIRCUIT — 12

R S FLIP FLOP — 4

R Q D
S

F

LOAD — 9

V

MULTI-VIBRATOR — 8

E

TRIAC/SCR — 14

60HZ LINE POWER — 7

A

120HZ "O" CROSSING DETECTOR — 6

B

FIGURE 6   (SECOND EMBODIMENT)

SCR / TRIAC POWER CONTROLLER

INPUT VOLTAGE ANALOG

VOLTAGE TO FREQUENCY CONVERTER

LOAD

TRIAC/ SCR

MONOSTABLE MULTI-VIBRATOR

OR GATE

ACTUAL RUNT POWER

RS FLIP FLOP

AND GATE

60 HZ "0" CROSSING DETECTOR

60 HZ LINE POWER
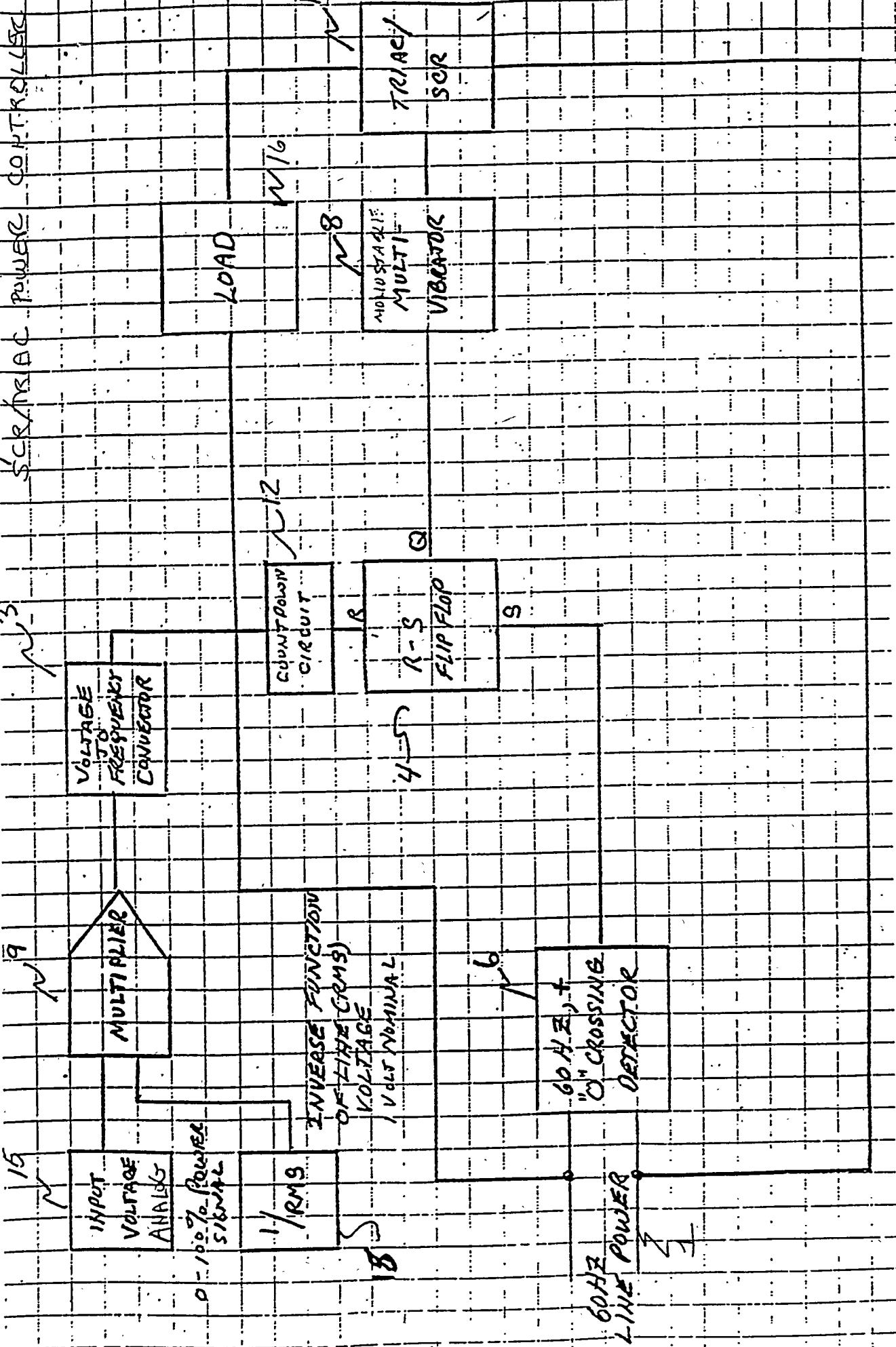
FIGURE 7
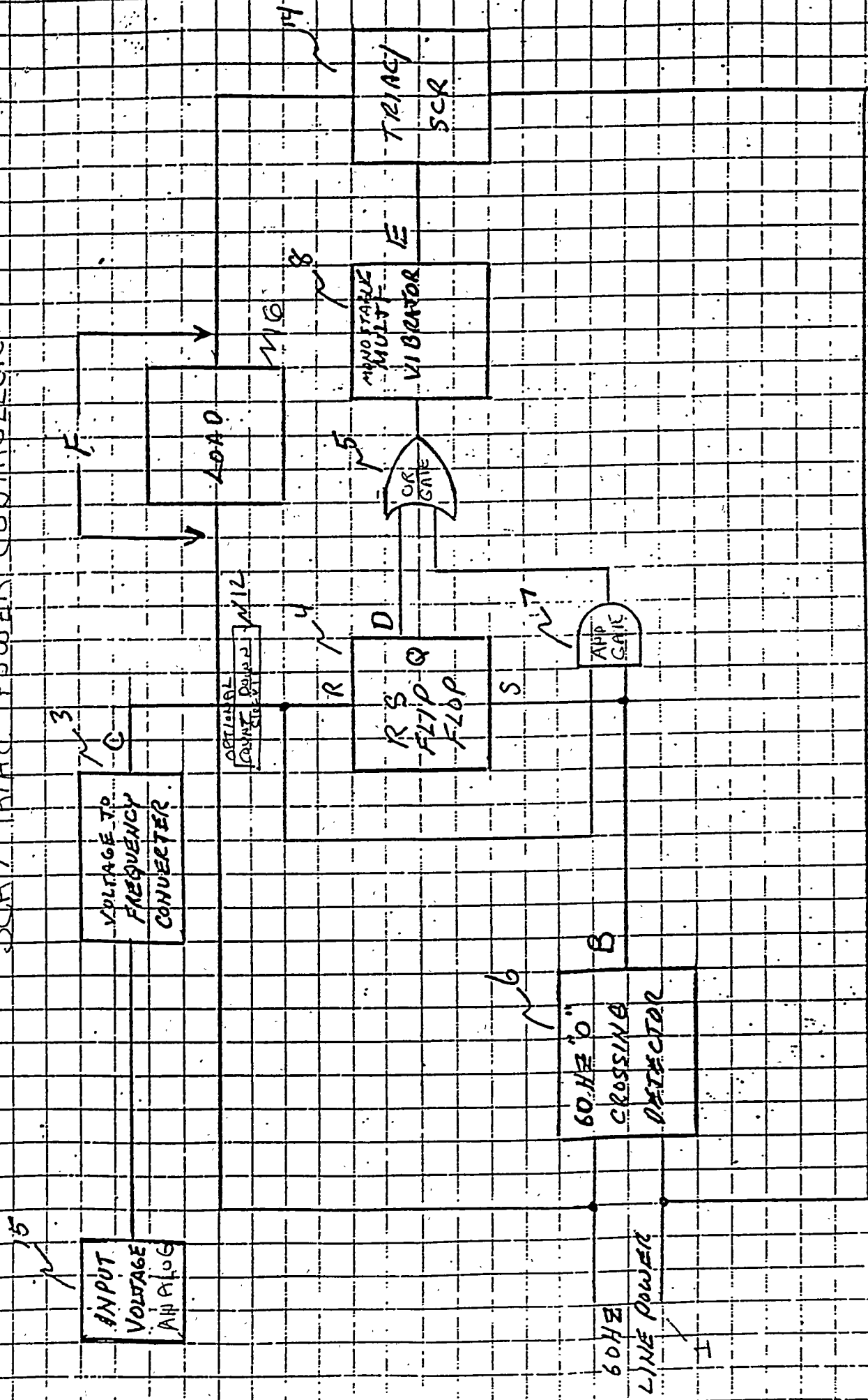
THIRD EMBODIMENT

SCR/TRIAC POWER CONTROLLER

FOURTH EMBODIMENT

FIGURE 8

SCR/TRIAC POWER CONTROLLER

FIGURE 9

FIFTH EMBODIMENT