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(54) TIME-DELAY SWITCHING CIRCUITS

(71) We, TEXAS INSTRUMENTS INCORPORATED, a Corporation organized according to the laws of the State of Delaware, United States of America, of 13500 North Central Expressway, Dallas, Texas, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The invention relates to time-delay switching circuits.

Accordingly, it is an object of the present invention to provide an improved time-delay switching circuit.

According to the present invention, there is provided a time-delay switching circuit comprising; a threshold device having a conductive and a non-conductive state and including at least three input leads, a first battery providing a first voltage source electrically connected to the first input lead of said device, a load electrically connected to the second input lead of said device, a second battery providing a second voltage source, a third battery providing a third voltage source interconnected in electrical opposition to said second battery with the combined voltage output of said second and third batteries being electrically interconnected to the third input lead of said device, the voltage output of said third battery being predictably reducible over a period of time such that the combined voltage output of said second battery and reduced voltage output of said third battery will be effective to produce a potential at said third input lead after a predetermined time period that changes the state of said device from non-conductive to conductive and thereby completes a circuit from said first battery to said load.

As used herein, the term "battery" embraces a single cell.

By way of example only, certain illustrative embodiments of the invention will now be

described with reference to the accompanying drawings, in which like reference numerals and symbols designate like parts through the Figures thereof, and in which:

FIGURE 1 is a schematic diagram illustrating a time-delay switching control circuit embodying the present invention.

FIGURE 2 is a graph illustrating voltage versus time waveforms at certain points in the circuit illustrated in FIGURE 1.

FIGURES 3 through 7 are schematic diagrams illustrating other embodiments of the invention wherein the energizer portion of the control circuit is located at different points in said circuit.

Referring now to FIGURE 1, there is illustrated a control circuit 10 comprising a threshold detector or gated switch 12 which may be, by way of example, a semiconductor controlled rectifier (SCR) having anode, cathode and gate electrical leads, 14, 16 and 18, respectively. A property of a semiconductor controlled rectifier is that it is nonconducting until a certain threshold potential is applied to its gate lead, after which it is rendered conducting or energized and will so remain until power is removed from the circuit that includes its cathode and anode. By way of example, an SCR that will operate in the circuit of FIGURE 1 is Texas Instruments Incorporated TIC-44. Leads 14, 16 and 18 of SCR 12 (the latter being identified in the drawings solely by the number 12) are connected to terminals 20, 22 and 24, respectively. Load 26 is connected to cathode 16 via terminal 22 and to ground via terminal 28. A first energy source 30 of V_1 volts, for example, has its negative side connected to ground through terminal 28 while its positive side is connected by way of terminal 32 to switch 34 via contact arm 36. Contact 38 of switch 34 is connected to the positive side of a second energy source 40 of V_2 volts, for example, while the negative side of source 40 is electrically connected with gate lead 18 of

rectifier 12 via terminal 24. Also connected to terminal 24 is one lead of impedance means 42 which, for example, may be a variable resistor, while the other lead of said impedance means is connected to contact 44 of switch 46. Impedance 42 is thus connected in parallel with energy source 40, a feature which is important in the operation of the embodiment. Contact arm 48 of switch 46 is connected to terminal 32 and to the negative side of energy source 50, for example, a voltage supply of E_1 volts. The positive side of said voltage supply 50 is electrically connected with anode 14 of rectifier 12 via terminal 20. Energy sources 30, 40 and 50 may be, by way of example, solid-state batteries, nickel cadmium batteries, or mercury cells while switches 34 and 46 may be of the single pole, single throw type made by ALCO, model MST-105E.

In operation, with switches 34 and 46 open, rectifier 12 is initially nonconducting since no potential is present on its gate lead 18. Accordingly, no power is supplied to load 26. For explanation purposes, it will be assumed that a threshold level of approximately V_s volts (see Figure 2) which produces a gate trigger current (I_{gt}) at gate terminal 24 will be required to energize rectifier 12, and thereby complete the circuit to load 26. Also, voltage V_1 from source 30 will be assumed to be approximately equal to voltage V_2 from source 40. When both switches 34 and 46 are closed at time $t_1=0$ (see Figure 2), initially the potential at gate terminal 24 is approximately zero since voltages V_1 and V_2 are approximately equal, opposite in polarity and connected in series between terminals 24 and 28. Furthermore, the voltage at cathode terminal 22 is also approximately zero since no definable current is flowing through load 26. The result is that the initial gate-to-cathode voltage of rectifier 12 is near zero and under this condition the rectifier is in a nonenergized or nonconducting state.

In order to change the state of rectifier 12 from nonconducting to conducting (and thereby supply power to the load 26), the potential at gate terminal 24 must be greater than that existing at cathode 16, i.e., the gate-to-cathode junction must be forward biased. This is accomplished by depleting or discharging the voltage V_2 of source 40 which is bucking out or neutralizing the voltage V_1 of source 30. Voltage V_2 of source 40 is depleted at a predetermined time period after the closure of switch 46 by the passage of current I (shown in Figure 1) through impedance means 42. The time t_2 for energy source 40 to become depleted to a level where rectifier 12 is energized (V_s of Figure 2) is dependent upon the shunt load across energy source 40, which is primarily defined by impedance means 42 (assuming the impedance of impedance means 42 is substantially larger

than the internal impedance of source V_2) as well as the decay rate or capacity of the battery, assuming that energy source 40 is a battery. This predetermined time period t_2 for the rectifier 12 to be energized may be expressed by the following equation:

$$t_2 \text{ (hours)} = \frac{CR_{42}}{V_2} \quad (1)$$

in which the capacity C (in ampere hours) is defined for source 40 when the absolute magnitude of the difference between source 30 of V_1 volts and the decaying voltage of energy source 40 of V_2 volts at least equals the absolute magnitude required to render rectifier 12 conductive (i.e., $V_1 - V_2 = V_s$ in Figure 2), and R_{42} is the value of impedance means 42 in ohms. Assuming that impedance means 42 is a variable resistor, the time required for energy source 40 to be discharged or depleted will thus vary directly with the value of resistor 42; that is, as resistor 42 is increased t_2 is increased. The time period t_2 may not only be varied or calibrated by varying the value of resistor 42, but also by pre-draining, pre-discharging or pre-depleting the capacity C of source 40 by a predetermined amount, which additionally aids in varying t_2 .

Referring specifically to FIGURE 2, it can be seen that at time t_1 when switches 34 and 46 are closed, the net voltage at terminal 24 or gate 18 is zero since voltages V_1 and V_2 are equal in magnitude and opposite in polarity. Although the magnitude of energy sources 30 and 40 have been illustrated in FIGURE 2 as being substantially equal in magnitude, the essential requirement for energizing the threshold device 12 is that the absolute value of the difference between voltages V_1 and V_2 equal or exceed the threshold level (V_s) of the switch or threshold device 12. Accordingly, voltages V_1 and V_2 may initially be unequal in magnitude within the purview of this invention but, for explanation and illustration purposes, have been shown as being substantially equal. As source 40 becomes depleted or discharged from its initial value V_2 through resistor 42 by the passage of current I through said resistor, its magnitude decreases at a rate which depends not only upon the value of resistor 42 but also its decaying or capacity characteristics. As energy source V_2 is depleted, energy source 30 is no longer completely neutralized, so that the net combined output voltage which appears at terminal 24 (that is, gate 18) increases in positive magnitude and approaches V_s , the threshold level of rectifier 12. At time t_2 (determined by the above equation), rectifier 12 will begin conducting through load

under the driving potential of $E_1 + V_1$ volts.

Switches 34 and 46 may be ganged. Sources 30, 40 and 50 may all be batteries of the mercury cell type. Also within the practice of this invention for certain applications, switch 34 may be omitted from FIGURE 1 and terminal 38 extended and connected to lead 32. Switch 34 cooperates to avoid unwanted depletion of the batteries by leakage currents when the batteries are first inserted into the circuit.

By way of example, the following are typical values for certain components of the circuit shown in FIGURE 1 according to one suitable form of the present invention:

	Source 30	1.3 volts
	Source 40	1.3 volts
	Source 50	2.6 volts
20	Resistor 42	26,000 ohms
	I	50 microamperes
	Capacity C	36 milliampere hours
	V_s	0.65 volt
	I_{GT}	20 microamperes
25	t_2	30 days

FIGURE 3 is another embodiment of the invention of FIGURE 1 in which the negative side of source 50 is connected directly to terminal 28 instead of being electrically connected with source 30 and switches 34 and 46. This arrangement is desirable if source 30 of V_1 volts has small current handling capacity and load 26 requires high currents therethrough, for example, an incandescent light bulb. In this case, when threshold device 12 is conducting through load 26, it will be under the driving potential of E_1 volts only and large currents passing through load 26 will not affect source 30. Load 26, it should be noted, is connected between the positive (+) side of source 50 and the threshold device 12. This arrangement is equally applicable to the other embodiments disclosed herein.

FIGURE 4 illustrates another embodiment of the invention illustrated in FIGURE 1. In the circuit according to FIGURE 4, the positive terminal of source 40 is connected directly to ground via terminal 28 while the negative side of source 40 is connected to the negative side of source 30 as well as to one side of switch 46. The positive side of source 30 is connected both to the negative side of voltage supply source 50 as well as to gate terminal 24. Variable impedance 42 is connected in parallel across source 40, one lead of said impedance being electrically connected to ground while the other lead is connected to contact 44. Anode terminal 20 of threshold device 12 is connected to the positive side of voltage supply 50 while the load 26 is electrically interconnected with cathode terminal 22 and ground terminal 28. In operation, the circuit shown in FIGURE 4

performs in the same manner as that described for the circuit shown in FIGURE 1. Upon closure of switch 46, source 40 of V_2 volts will be depleted at a predetermined rate dependent upon the value of impedance 42 and the capacity C of source 40, thereby allowing the combined voltage at gate terminal 24 to rise until it at least equals V_s (see FIGURE 2), at which time rectifier 12 is energized and completes the circuit to load 26. Time t_2 is calculated from equation (1) above as described in reference to FIGURE 1.

FIGURE 5 illustrates still another embodiment of the invention wherein impedance means 42 is electrically connected from gate terminal 24 to anode terminal 20, i.e., across source 40 and source 50. After closure of switch 52, a current I will flow through impedance means 42 dependent upon the value of E_1 , V_2 and impedance means 42. Equation (1) above will be valid in the circuit of FIGURE 5 for t_2 except that the denominator V_s shown in equation (1) will be replaced by $V_2 + E_1$. In operation, the current I will flow as indicated in FIGURE 5 depleting both sources 40 and 50 until the voltage of source 40 has depleted or discharged an amount such that the combined voltage or V_1 plus the depleted voltage V_2 is sufficient to produce a gate trigger current to turn device 12 from a nonconducting to a conducting state. In this form of the invention, the capacity of source 50 must be greater than that of source 40 in order that when threshold device 12 is energized there is sufficient voltage and current capacity remaining in source 50 to supply power to load 26.

FIGURE 6 illustrates yet another embodiment of the invention, wherein threshold or bistable device 12 is comprised of two transistors, pnp transistor 54 and npn transistor 56. Transistors 54 and 56 could be, by way of example, Texas Instruments Incorporated transistors 2N3702 and 2N3704, respectively. Threshold device 12 has three output leads connected to various terminals, namely the emitter lead of transistor 54 connected to terminal 20, the emitter lead of transistor 56 connected to terminal 22 and the collector of transistor 54 and base of transistor 56 connected to terminal 24. The base of transistor 54 is connected to the collector of transistor 56. One side of resistor 42 is connected to terminal 24 while the other side is connected to the negative side of source 50 and one side of switch 58. Source 40 is connected to terminal 24 and the other side of switch 58.

The operation of the transistor threshold detector 12 shown in FIGURE 6 is similar to that of the SCR threshold detector circuit shown in FIGURE 1. Initially, both transistors 54 and 56 are nonconducting since the voltage at terminal 24 is essentially at zero (assuming V_1 is approximately equal to V_s). Furthermore, the voltage at terminal 22 is

essentially zero since no definable current is flowing through load 26. Switch 58 is closed at time $t_1=0$ (see Figure 2). A current I flows through impedance means 42 as shown which depletes source 40. At time t_2 , defined by equation (1) above, the voltage of source 40 has discharged to a point such that the algebraic sum of voltages V_1 plus V_2 at least equals V_0 , the threshold level of threshold device 12 (see Figure 2). When the voltage at terminal 24 at least equals V_0 , the collector of transistor 56 begins to draw current through the base of transistor 54 and through regenerative action transistors 54 and 56 begin to conduct thereby supplying power to load 26.

FIGURE 7 illustrates still another embodiment of the invention and is the same as FIGURE 5 except that impedance 42 and switch 58 have been omitted while switch 60 is interconnected between the positive side of source 40 and the negative side of source 50 (which is also electrically connected to the positive side of source 30). Sources 30 and 40 are opposite in polarity and are of such magnitude that the absolute magnitude of the difference between V_1 and V_2 does not equal the threshold level of bistable device 12. Assume that electrical source 40 has a definable natural decay or discharge rate. After a predetermined time period which is dependent upon that decay rate or shelf life, the absolute value of the difference between V_1 and the decaying V_2 will at least equal the threshold value of bistable device 12, thereby energizing the device and allowing power to be supplied to load 26. It should be noted that source 30 may also be decaying at a second decay rate; the important consideration is that the combined decay rates are effective to produce an electrical potential at terminal 24 after a predetermined time period which at least equals the threshold level of device 12.

In summary, the described control circuits provide arrangements by which opposed voltage sources are utilized to generate a voltage that will increase in magnitude as one of the sources becomes depleted. These control circuits used in connection with a threshold detecting device as a reference, each provide a programmable reference with minimum complexity, which is simple, low cost, has a relatively small number of components, is adapted to mass production techniques and yet can be easily varied or calibrated to vary the time delay characteristics of the circuit. The depleted energy source should have a reasonably definable capacity as expressed by its ampere hour parameter which will allow depletion rate to define voltage versus operating life of the source.

Although the present invention has been shown and illustrated in terms of specific apparatus, it will be apparent that changes or

modifications can be made without departing from the scope of the invention as defined by the appended claims.

WHAT WE CLAIM IS:—

1. A time-delay switching circuit comprising: a threshold device having a conductive and a non-conductive state and including at least three input leads, a first battery providing a first voltage source electrically connected to the first input lead of said device, a load electrically connected to the second input lead of said device, a second battery providing a second voltage source, a third battery providing a third voltage source interconnected in electrical opposition to said second battery with combined voltage output of said second and third batteries being electrically interconnected to the third input lead of said device, the voltage output of said third battery being predictably reducible over a period of time such that the combined voltage output of said second battery and reduced voltage output of said third battery will be effective to produce a potential at said third input lead after a predetermined time period that changes the state of said device from non-conductive to conductive and thereby completes a circuit from said first battery to said load.

2. A circuit as set forth in Claim 1, wherein said third battery has a predetermined natural voltage decay rate such that the combined voltage output of said second battery and the decaying voltage output of said third battery will produce a potential at said third input lead after the predetermined time period that changes the state of said device from non-conductive to conductive.

3. A circuit as set forth in Claim 2, wherein said second battery has a predetermined natural voltage decay rate whereby the combined voltage decay rates of said second and third batteries are effective to produce a potential at said third input lead after the predetermined time period that changes the state of said device from non-conductive to conductive.

4. A circuit as set forth in Claim 1, further including impedance means electrically connected with said third battery for reducing the voltage output of said third battery, whereby the current flowing through said impedance means and said third battery substantially reduces the voltage output of said third battery over the predetermined time period such that the combined voltage output of said second battery and reduced voltage output of said third battery is effective to produce a potential at said third input lead after the predetermined time period that changes the state of said device from non-conductive to conductive.

5. A circuit as set forth in any of Claims 1 to 4, wherein the voltage output of said third



essentially zero since no definable current is flowing through load 26. Switch 58 is closed at time $t_1=0$ (see Figure 2). A current I flows through impedance means 42 as shown which depletes source 40. At time t_2 , defined by equation (1) above, the voltage of source 40 has discharged to a point such that the algebraic sum of voltages V_1 plus V_2 at least equals V_0 , the threshold level of threshold device 12 (see Figure 2). When the voltage at terminal 24 at least equals V_0 , the collector of transistor 56 begins to draw current through the base of transistor 54 and through regenerative action transistors 54 and 56 begin to conduct thereby supplying power to load 26.

FIGURE 7 illustrates still another embodiment of the invention and is the same as FIGURE 5 except that impedance 42 and switch 58 have been omitted while switch 60 is interconnected between the positive side of source 40 and the negative side of source 50 (which is also electrically connected to the positive side of source 30). Sources 30 and 40 are opposite in polarity and are of such magnitude that the absolute magnitude of the difference between V_1 and V_2 does not equal the threshold level of bistable device 12. Assume that electrical source 40 has a definable natural decay or discharge rate. After a predetermined time period which is dependent upon that decay rate or shelf life, the absolute value of the difference between V_1 and the decaying V_2 will at least equal the threshold value of bistable device 12, thereby energizing the device and allowing power to be supplied to load 26. It should be noted that source 30 may also be decaying at a second decay rate; the important consideration is that the combined decay rates are effective to produce an electrical potential at terminal 24 after a predetermined time period which at least equals the threshold level of device 12.

In summary, the described control circuits provide arrangements by which opposed voltage sources are utilized to generate a voltage that will increase in magnitude as one of the sources becomes depleted. These control circuits used in connection with a threshold detecting device as a reference, each provide a programmable reference with minimum complexity, which is simple, low cost, has a relatively small number of components, is adapted to mass production techniques and yet can be easily varied or calibrated to vary the time delay characteristics of the circuit. The depleted energy source should have a reasonably definable capacity as expressed by its ampere hour parameter which will allow depletion rate to define voltage versus operating life of the source.

Although the present invention has been shown and illustrated in terms of specific apparatus, it will be apparent that changes or

modifications can be made without departing from the scope of the invention as defined by the appended claims.

WHAT WE CLAIM IS:—

1. A time-delay switching circuit comprising: a threshold device having a conductive and a non-conductive state and including at least three input leads, a first battery providing a first voltage source electrically connected to the first input lead of said device, a load electrically connected to the second input lead of said device, a second battery providing a second voltage source, a third battery providing a third voltage source interconnected in electrical opposition to said second battery with combined voltage output of said second and third batteries being electrically interconnected to the third input lead of said device, the voltage output of said third battery being predictably reducible over a period of time such that the combined voltage output of said second battery and reduced voltage output of said third battery will be effective to produce a potential at said third input lead after a predetermined time period that changes the state of said device from non-conductive to conductive and thereby completes a circuit from said first battery to said load.

2. A circuit as set forth in Claim 1, wherein said third battery has a predetermined natural voltage decay rate such that the combined voltage output of said second battery and the decaying voltage output of said third battery will produce a potential at said third input lead after the predetermined time period that changes the state of said device from non-conductive to conductive.

3. A circuit as set forth in Claim 2, wherein said second battery has a predetermined natural voltage decay rate whereby the combined voltage decay rates of said second and third batteries are effective to produce a potential at said third input lead after the predetermined time period that changes the state of said device from non-conductive to conductive.

4. A circuit as set forth in Claim 1, further including impedance means electrically connected with said third battery for reducing the voltage output of said third battery, whereby the current flowing through said impedance means and said third battery substantially reduces the voltage output of said third battery over the predetermined time period such that the combined voltage output of said second battery and reduced voltage output of said third battery is effective to produce a potential at said third input lead after the predetermined time period that changes the state of said device from non-conductive to conductive.

5. A circuit as set forth in any of Claims 1 to 4, wherein the voltage output of said third

battery is substantially equal to the voltage output of said second battery at the beginning of the predetermined time period.

5 6. A circuit as set forth in Claim 4, wherein said impedance means is a resistor in parallel with said third battery.

7. A circuit as set forth in Claim 6, wherein said resistor is variable to vary said predetermined time period.

10 8. A circuit as set forth in either of Claims 6 or 7, wherein said predetermined time period is defined by

$$\frac{CR}{V},$$

15 where C is the ampere hour capacity of said third battery determined for the combined voltage output of the second battery and the reduced voltage output of the third battery to be effective to produce the potential at said third input lead required to render the
20 state of said device conductive,

R is the total resistance of the resistor in parallel with said third battery, and

V is the voltage output of said third battery at the beginning of the predetermined time period.

25 9. A circuit as set forth in any preceding Claim, wherein said threshold device is a semiconductor controlled rectifier.

10. A circuit as set forth in any of Claims 1 to 8, wherein said threshold device is a transistor threshold device.

11. A time-delay switching circuit for energizing a threshold device with a threshold signal, the circuit being substantially as herein described with reference to and as illustrated by Figures 1 and 2, Figure 3, Figure 4, Figure 5, Figure 6 or Figure 7 of the accompanying drawings.

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