

[54] **ENERGY STORAGE METHOD AND APPARATUS**
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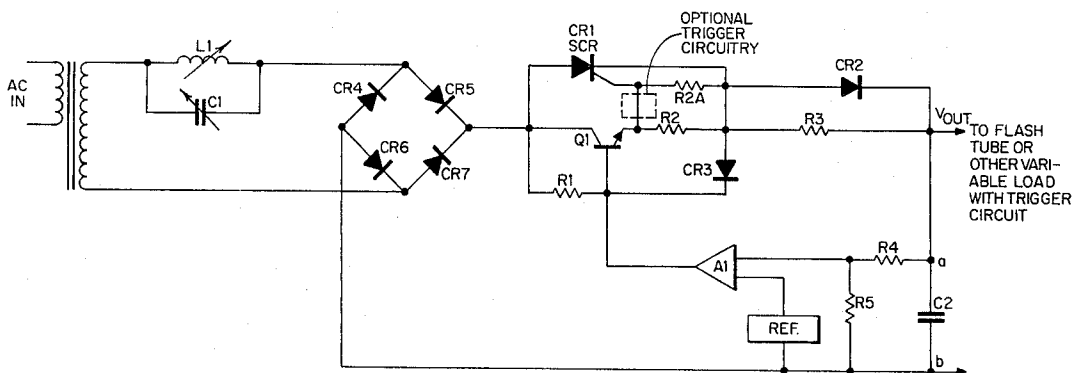
Primary Examiner—A. D. Pellinen
Attorney, Agent, or Firm—Rines and Rines; Shapiro and Shapiro

[52] **U.S. Cl.**..... 321/13, 320/22, 321/18, 323/22 T, 323/25
[51] **Int. Cl.**..... **G05f 1/58**
[58] **Field of Search**..... 317/33 R, 33 SC; 320/22, 320/39, 40; 321/11, 12, 13, 16, 18; 323/22 T, 23, 25; 307/93

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2,967,991 1/1961 Deutch 323/23 X

[57] **ABSTRACT**
A novel energy storage element charging technique wherein a transistor or similar series pass element in the charging circuit is automatically by-passed by a high-current SCR non-linear circuit during high charging currents, and serves thereafter to regulate the stored voltage. The technique is also useful for over-current protection in conventional regulated power supplies.

13 Claims, 2 Drawing Figures



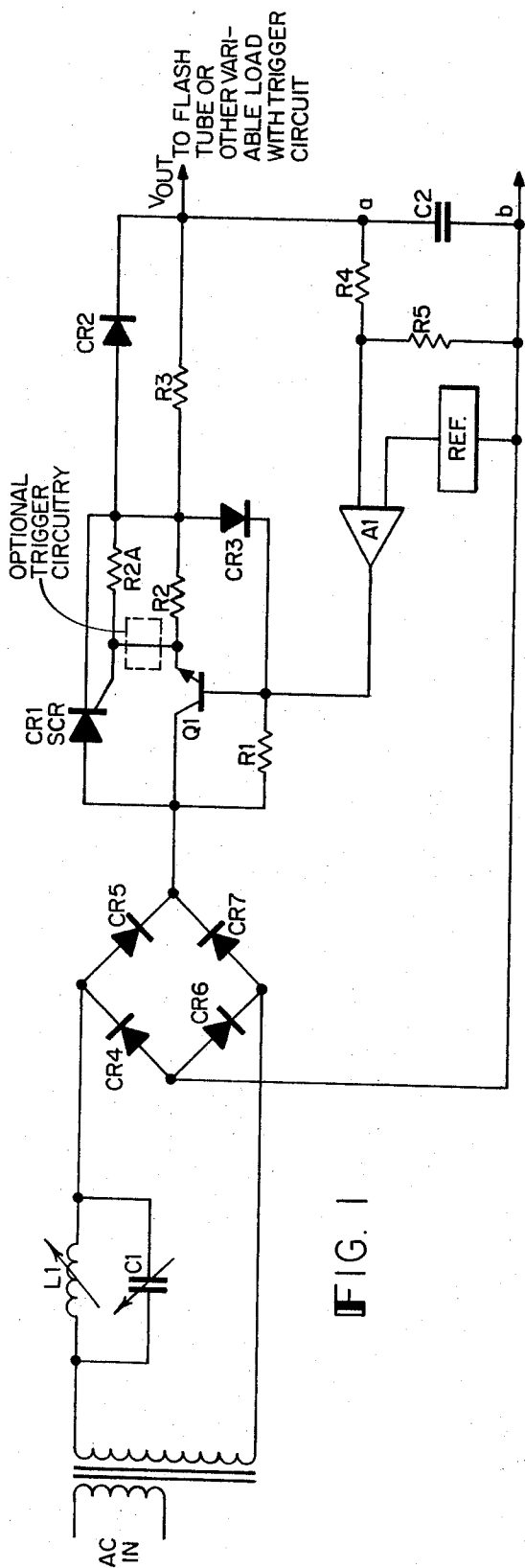


FIG. 1

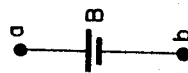


FIG. 2

tor(s) C_2 ; this operation repeating each half cycle of the a.c. input voltage until the output voltage (V_{out}) substantially reaches the level predetermined by R_4 , R_5 and the reference voltage REF.

At such time, amplifier A_1 will remove the heavy drive from Q_1 , and the by-pass switching element CR_1 will no longer be rendered conductive at the start of each a.c. half cycle. The pass element Q_1 will now pass the much lower currents necessary to regulate the voltage stored in C_2 , keeping the charging thereof replenished despite the bleeder drain current through R_4 and R_5 . In case of an overcharge of C_2 , amplifier A_1 will discharge C_2 until the desired voltage level is reached, through a path including R_3 and a further diode CR_3 connected from the junction of R_2 and R_3 to the base of Q_1 , such base being also connected through further resistance R_1 to the input to the pass element.

Thus, an automatic by-passing of the series pass-element linear charging circuit is effected during initial and high-current charging, through CR_1 and the non-linear circuit including CR_2 ; and, when the desired energy storage in C_2 is attained, the series linear circuit only, thereupon takes over and thereafter regulates and maintains the stored voltage. This, of course, greatly reduces the current-passing and power dissipation requirements of the transistor or similar pass element Q_1 , eliminating the essential requirement for pluralities of the same and for copious heat sink and other dissipation devices, as before discussed and also reducing the hazard of secondary breakdown in Q_1 .

The charging procedure will, of course, repeat after the capacitor(s) C_2 discharges through the load, such as a flash tube, upon its being triggered, as previously discussed and as is explained, for example, in said flash apparatus Letters Patent. Despite extreme load variations from conductive to non-conductive loads, such as flash tubes or the like, the conventional power dissipation requirements on series pass elements has thus been remarkably obviated by the present invention.

Reference was previously made to the use of the invention for battery charging applications, also. In such, the capacitor(s) C_2 may, for example, be replaced by a discharged storage battery B, as shown in FIG. 2, the battery being connected between terminals a and b of FIG. 1 instead of the capacitor(s) C_2 . This circuit will then serve to rapidly charge the battery through CR_1 and, upon reaching the desired battery voltage, will change over to "trickle charge" through Q_1 , with the cross-over voltage being very accurately determined by R_4 , R_5 and REF, as before.

If desired, the a.c. source may feed a parallel network L_1 - C_1 in the charging circuit prior to the rectifier stage to allow an improved charging time for C_2 without increasing the initial charging current. Inductance L_1 is adjusted to establish such initial charge current when the voltage across C_2 is substantially zero. Charging capacitor C_1 is adjusted to reduce the charge time to the desired stored voltage, with the impedance of C_1 being selected to be much larger than, preferably about ten times, that of L_1 at the a.c. input line frequency, and with C_1 helping to reduce its charge time by resonating with L_1 at a frequency higher than the line frequency. In this operation, at a stored or output voltage across C_2 (V_{out}) greater than zero, when time gaps exist between charge current pulses each half cycle, L_1 and C_1 will resonate to reverse the voltage during such time gaps, such that the energy stored in C_1 during a charge

current pulse will be available at the beginning of the next charge pulse in polarity, which will aid the transistor with secondary voltage. The addition of capacitor C_1 to the inductor L_1 , moreover, reduces the initial (peak) line current and makes it substantially more constant during the charge cycle. It is this constancy which permits the charge of C_2 in the time allowed without exceeding a maximum line current specification. It would not be possible to do this without C_1 using only L_1 , or with resistance replacing L_1 .

In practice, suitable pass elements Q_1 , SCR switching elements CR_1 and diode elements CR_2 for such charging circuits up to 500 volts have been types DTS801, 2N4101 and IN4007, respectively.

If desired, optional conventional trigger circuits, including those described in said flash-apparatus Letters Patent, may also be used at the gate of CR_1 for control of trigger drive shape and timing. Further modifications will also occur to those skilled in this art and all such are considered to fall within the spirit and scope of the invention as defined in the appended claims.

What is claimed is:

1. A method of reducing power dissipation under wide load variations in energy storage through a series pass linear path from an a.c. voltage source, that comprises, initially passing pulsating rectified a.c. current from said source through the linear path to start the energy storage; automatically responding to the initial relatively high current from said source through said linear path to by-pass said series pass linear path by a non-linear high-current path each half-cycle of the a.c. voltage repetitively until substantially full energy storage is attained; and thereupon and thereafter confining the current from said source to said series pass linear path while regulating the same to maintain the desired energy storage.

2. A method as claimed in claim 1 and in which said regulating comprises feeding back a sample of the stored energy to control the conduction and thus impedance of the series pass linear path.

3. A method of reducing power dissipation under wide load variations in capacitor energy storage systems through a relatively low-current series pass linear path from an a.c. voltage source, that comprises, initially passing pulsating rectified a.c. current from said source through the linear path to start the capacitor charging and the resulting energy storage; automatically responding to the initial relatively high current from said source through said linear path to by-pass said series pass linear path by a non-linear high current path each half-cycle of the a.c. voltage repetitively until substantially full charging and energy storage is attained; and thereupon and thereafter confining the current from said source to said series pass linear path while regulating the same to maintain the desired energy storage.

4. An energy storage apparatus having, in combination, an a.c. voltage source provided with means for producing pulsating rectified voltage therefrom; storage means; a linear circuit connecting said source to said storage means through series pass means; regulating feed-back circuit means connected from said storage means to said pass means to control the impedance thereof; relatively high-current switching means connected, when effective, to form a non-linear high-current energy storage path; means responsive to the initial high current in the linear circuit from said source

ENERGY STORAGE METHOD AND APPARATUS

The present invention relates to energy storage methods and apparatus, being broadly concerned with the problems of power dissipation and the like underlying the use of series pass regulating elements, including transistors, in power supplies, including battery chargers; and, more particularly, though not exclusively, with power supplies of the type used in capacitor charging-and-discharging pulse-producing circuits, as in stroboscopy, electronic flash applications, radar and the like.

For illustrative purposes the invention will be described with reference to the examples of such pulse or flash-producing energy storage and discharge circuits, though, as before stated, it is of broader utility, as well. Where regulation is desired in power supplying capacitor storage systems, resort to linear series pass elements, such as transistors or other similar elements, has been accompanied by serious problems in power dissipation, often requiring the use of pluralities of such pass elements and in copious heat-dissipating sinks and other structures (U.S. Pat. No. 2,942,172; Kepco Power Supplies Catalog B-657, 1965, Kepco, Inc.). Such techniques and structures are particularly limiting in the case of stroboscopic or other electronic flash apparatus and the like, such as those described, for example, in U.S. Pat. Nos. 3,355,625; 3,286,128; 2,977,508.

While the present invention in preferred form embodies SCR switching elements and pass transistors and the like, these are employed in an entirely novel combination producing radically new results. In, for example, U.S. Pat. No. 3,517,294, and though a combination of SCR and pass transistor is employed and it is endeavored to provide a multiple state charge method, the connection of SCR and pass transistor is not at all similar to that of the present invention; i.e., it does not use pass transistor current to turn on the SCR and it does not continuously regulate voltage output when the SCR is off (during trickle charge). Rather, it is an oscillating tri-state system highly dependent on storage battery characteristic to function properly, and does not regulate in the trickle mode. Similarly, in U.S. Pat. No. 3,456,125, although the circuit configuration is somewhat similar, the method of developing the SCR gate voltage is so different as to completely change the "protection" function of the SCR against sudden shorts. In accordance with the present invention, on the other hand, the circuit provides protection against normally expected overloads of all types and is not dI/dt sensitive, automatically sensing when to cease with the SCR and revert to linear regulation. Other approaches, similarly foreign to the invention and incapable of providing the results thereof, include U.S. Pat. Nos. 3,141,124; 3,591,830; 3,427,501; 2,992,385; 3,359,434; and 3,365,645.

It is accordingly an object of the present invention to obviate such problems, providing a new and improved method of and apparatus for greatly reducing the power dissipation and related deleterious requirements in capacitor energy storage circuits, including those employing relatively low-current series pass elements and the like.

A further object is to provide a novel capacitor (and/or battery) charging and discharging pulse-producing apparatus.

Still an additional object is to provide a novel flashing apparatus for such purposes as the before-mentioned stroboscopy, electronic pulsing or flashing and the like.

Other and further objects will be explained hereinafter and are more particularly pointed out in the connection with the appended claims.

In summary, however, from one of its important aspects, the invention contemplates a method of reducing power dissipation under wide load variations in capacitor, battery and similar energy storage through series pass linear path from an a.c. voltage source. While the series pass linear path may include a relatively low-current pass element, the linear element can permit high currents, but may also have appreciable voltage drop and, hence, high dissipation. Transistors are particularly sensitive to high voltage and high current conditions and may suffer "secondary breakdown" with catastrophic results. The technique of the invention comprises initially passing pulsating rectified a.c. current from said source through the linear path to start such capacitor or battery or similar charging and the resulting energy storage; responding to the initial relatively high current from said source through said linear path (when circuit linearity is not needed for regulation) to by-pass said series pass linear path by a non-linear high current path each half-cycle of the a.c. voltage until substantially full charging and energy storage is attained; and thereupon and thereafter confining the current from said source to said series pass linear path while regulating the same to maintain the desired energy storage. Preferred apparatus and details follow.

The invention will now be described with reference to the accompanying drawing, wherein;

FIG. 1 is a circuit diagram of a preferred embodiment, particularly adapted for pulsing or flashing applications; and

FIG. 2 is a modification for battery charging.

Referring to FIG. 1 of the drawing, the storage capacitor(s) of a power supply for such an application is shown at C_2 , adapted to be connected across a normally non-conductive load, such as a flash tube or the like, so-labelled, provided with conventional trigger circuit means to render the load conductive, as described in said flash-apparatus Letters Patent, for example, to discharge the energy stored in C_2 through the conductive load to produce a pulse or flash for such purposes as stroboscopy, flash photography or the like. The charging or energy storage circuit for C_2 is shown comprising a linear circuit path containing a series pass element, such as a transistor Q_1 , connected between its collector and emitter electrodes in such series circuit through resistances R_2 and R_3 . An a.c. voltage source, labelled "AC In," feeds a bridge rectifier (CR_4 through CR_7) to start charging C_2 through the pass element Q_1 . An amplifier A_1 compares the initial voltage developed on C_2 , divided by the voltage-divider chain R_4 and R_5 , with a reference voltage (REF) and, of course, determines that such is low, controlling the base of Q_1 to cause it to conduct. Relatively high current will flow through R_2 , causing the triggering of the gate of a normally ineffective non-conductive high-current SCR switching element CR_1 or the like, thus by-passing Q_1 with a very low impedance path through the conductive SCR. With the network elements comprising $R_{2,4}$ and diode CR_2 connected across R_2 and R_3 , respectively, the charging current will now flow through the non-linear path comprising CR_2 to charge storage capaci-

through said series pass means upon initiation of energy storage for rendering said switching means effective to by-pass said series pass means each half cycle of the said a.c. voltage repetitively until the energy storage is substantially completed and for thereupon maintaining said switching means ineffective such that the current from said source is thereupon and thereafter passed from said source through the regulated series pass linear circuit, thereby to maintain the energy storage at the desired level.

5. Apparatus as claimed in claim 4 and in which said energy storage means comprises capacitor means.

6. Apparatus as claimed in claim 4 and in which said energy storage means comprises battery means.

7. A capacitor charging and storage apparatus having, in combination, an a.c. voltage source provided with means for producing pulsating rectified voltage therefrom; storage capacitor means; a relatively low-current linear circuit connecting said source to said capacitor means through series pass means; regulating feed-back circuit means connected from said capacitor means to said pass means to control the impedance thereof; relatively high-current switching means connected, when effective, to form a non-linear high-current charging path; means responsive to the initial high-current in the low-current linear circuit from said source through said series pass means upon initiation of charging for rendering said switching means effective to by-pass said series pass means each half cycle of the said a.c. voltage repetitively until said capacitor means is substantially charged and for thereupon maintaining said switching means ineffective such that the current from said source is thereupon and thereafter passed from said source through the regulated series pass linear circuit, thereby to maintain the capacitor storage at

the desired level.

8. Apparatus as claimed in claim 7 and in which said series pass means comprises transistor means and said switching means comprises SCR means connected to respond to high current in said linear circuit.

9. Apparatus as claimed in claim 8 and in which means is provided to discharge said capacitor means and thereupon repeat said charging.

10. Apparatus as claimed in claim 9 and in which said transistor means has collector, emitter and base electrodes and is connected with said collector and emitter in series with resistance in said linear circuit and said base connected with said regulating feed-back circuit means; and said SCR means has anode, cathode and gate electrodes and is connected with said anode and cathode in parallel with said collector, emitter and resistance, and with said gate connected to a point of said linear circuit to respond to the voltage developed across said resistance.

11. Apparatus as claimed in claim 10 and in which diode means is connected between said resistance and said base.

12. Apparatus as claimed in claim 10 and in which diode means is connected between said SCR and said capacitor means.

13. Apparatus as claimed in claim 10 and in which said source connected in the charging circuit comprises a parallel inductance-capacitance network the inductance of which is adjusted to establish the initial maximum charging current and the capacitance of which is adjusted to reduce the charge time, the said capacitance being further adjusted to resonate with said inductance means at a frequency higher than that of the said a.c. voltage.

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