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REPLY TO
ATTN OF: GP

TO: USI/Scientific & Technical Information Division
Attention: Miss Winnie M. Morgan

FROM: GP/Office of Assistant General Counsel for Patent Matters

SUBJECT: Announcement of NASA-Owned U. S. Patents in STAR

In accordance with the procedures agreed upon by Code GP and Code USI, the attached NASA-owned U. S. Patent is being forwarded for abstracting and announcement in NASA STAR.

The following information is provided:

U. S. Patent No. : 3,571,699

Government or Corporate Employee : U.S. Government

Supplementary Corporate Source (if applicable) :

NASA Patent Case No. : ERC-10013

NOTE - If this patent covers an invention made by a corporate employee of a NASA Contractor, the following is applicable:
Yes ☐ No ☑
Pursuant to Section 305(a) of the National Aeronautics and Space Act, the name of the Administrator of NASA appears on the first page of the patent; however, the name of the actual inventor (author) appears at the heading of Column No. 1 of the Specification, following the words ". . . with respect to an invention of . . ."

Elizabeth A. Carter

Elizabeth A. Carter
Enclosure
Copy of Patent cited above

FACILITY FORM 602

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(CATEGORY)

N71-27053

PATENTED MAR 23 1971

3,571,699

FIG. 1

N71-27053 40%

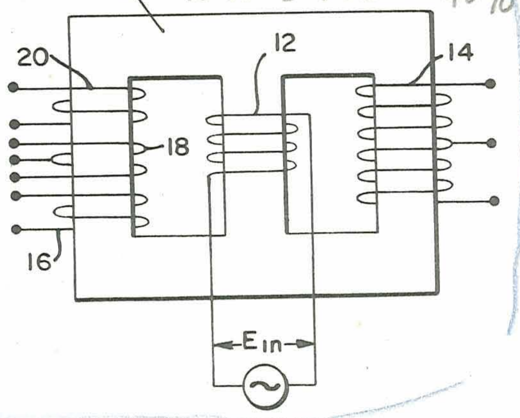


FIG. 2

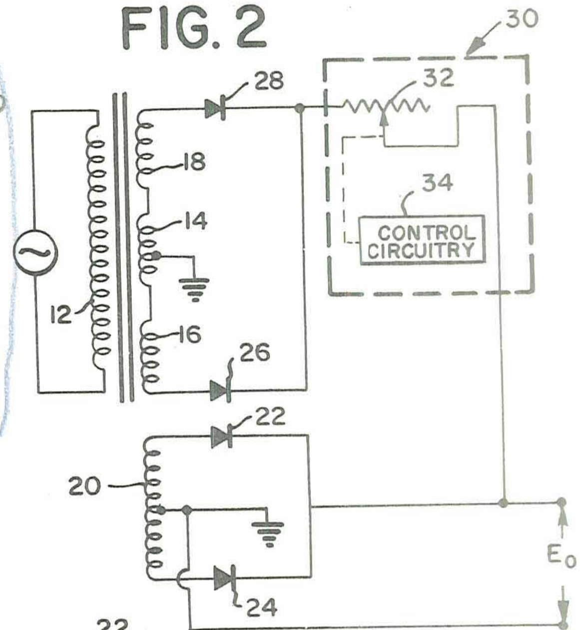


FIG. 4

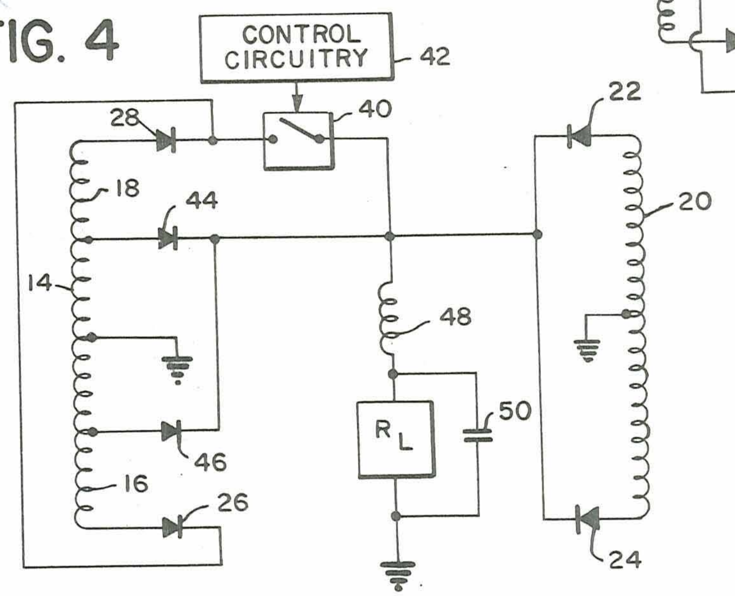


FIG. 5

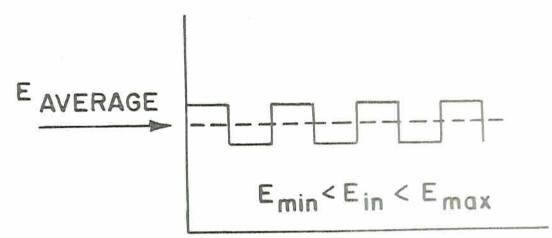
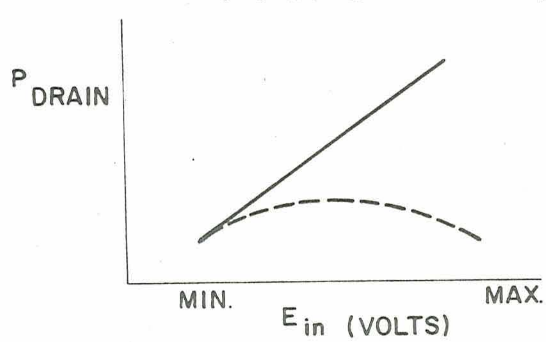


FIG. 3



INVENTOR
SHERWOOD THALER

BY Herbert E. Farmer

ATTORNEYS

1666

United States Patent

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[72] Inventor Sherwood Thaler
Lexington, Mass.
[21] Appl. No. 865,811
[22] Filed Oct. 13, 1969
[45] Patented Mar. 23, 1971
[73] Assignee The United States of America as represented by the Administrator of the National Aeronautics and Space Administration

[54] **VOLTAGE REGULATOR**
3 Claims, 5 Drawing Figs.

[52] U.S. Cl. 323/48, 323/60
[51] Int. Cl. H01f 19/00, H01f 29/00
[50] Field of Search 323/48, 49, 57, 60, 61, 83, 87, 88; 321/57, 68; 336/155, 170, 180, 182, 214

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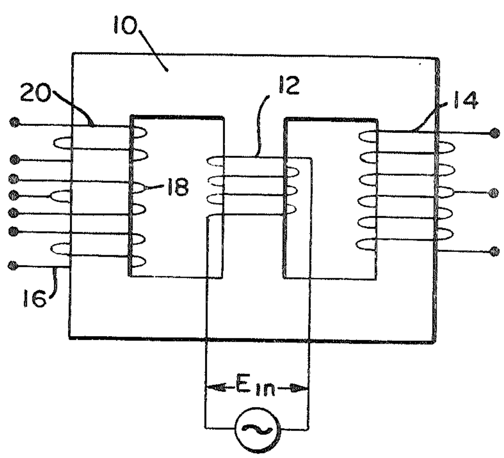
Primary Examiner—Gerald Goldberg
Attorneys—Marvin J. Marnack, Marvin F. Matthews and John R. Manning

ABSTRACT: Voltage regulators designed for connection in series with an alternating current source and a load and employing a three-leg, two-window transformer are disclosed. Secondary windings on the two outer transformer core legs are interconnected to form a pair of secondary winding systems and the systems are interconnected via a variable resistance. Voltage regulation is achieved by varying the flux distribution in the transformer core by employing variable resistance to distribute the load current between the winding systems.



VOLTAGE REGULATOR

ORIGIN OF THE INVENTION

The invention described herein was made by an employee of the United States Government and may be manufactured and used by or for the Government for governmental purposes without the payment of any royalties thereon or therefor.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to the regulation of the voltage applied to a load from an unregulated voltage source. More specifically, the present invention is directed to voltage regulator apparatus intended for connection in series with a source of alternating current and a load. Accordingly, the general objects of the present invention are to provide novel and improved methods and apparatus of such character.

2. Description of the Prior Art

Series regulators which may be connected between an unregulated, varying voltage source and a load and which will cause application of a constant output voltage to the load are well-known in the art. The typical prior art series regulator is a relatively inefficient device in that, in order to obtain output voltage regulation, it depends upon the steady-state dissipation of substantial amounts of power in an element connected in series with the load. Further, in prior art series regulators the power dissipated in the series element will vary directly with the source voltage. Accordingly, the power dissipation element must be sized so that it will dissipate the requisite power with the maximum expected input voltage without overheating and the element must also be able to dissipate a fair amount of power over long periods since it normally operates approximately midrange of the expected input voltage excursions. These design criteria, of course, add size and weight to the voltage regulator while calling for the wasteful dissipation of substantial amounts of power in the series connected element.

Also known in the art are switching-type series regulators which achieve a constant output voltage level by means of varying the duty cycle of switching elements connected between the source and load. Thus, through the use of suitable logic circuitry which senses the load voltage level, the series connected switching element may be caused to conduct or interrupt the power flow thereby coupling the source to the load theoretically with infinite or zero attenuation. As is well known, prior art switching regulators of the "on-off" type are characterized by an output with very high "ripple" and substantial switching transients superimposed thereon. While the ripple and transients can be removed from the output voltage by filtering, the weight and expense of the requisite filters prohibits the use of the switching regulator in many applications. Also, prior art switching regulators have the disadvantage of drawing discontinuous current from the source thereby requiring an input filter or other penalizing factors in the system configuration.

SUMMARY OF THE INVENTION

The present invention overcomes the foregoing and other disadvantages of the prior art by providing a novel series regulator which maintains, from an unregulated and varying input voltage, a constant output potential. The regulator of the present invention employs a novel transformer and circuit configuration which couples the unregulated source to a load in such a manner that the power dissipated in the regulator is at a minimum at both extremes of the normally expected source output voltage magnitude range. In accomplishing the foregoing, the present invention employs a transformer structure of the three-leg, two-window type. A primary winding connected to the voltage source is wound on the center leg of the transformer core and a plurality of secondary windings are wound on the outer core legs. Through the use of control circuitry and either a switch or series connected variable resistance, the flux distribution through the outer legs of the transformer core is controlled thereby controlling the voltage induced in the several secondary windings. Accordingly, by properly interconnecting the transformer secondary windings, the power coupled from the source to the load may be modulated, by varying the flux distribution in the transformer core to thereby add a variable amount of power to the minimum amount constantly being transmitted to the load, and the output voltage maintained at a preselected level.

BRIEF DESCRIPTION OF THE DRAWING

The present invention may be better understood and its numerous objects and advantages will become apparent to those skilled in the art by reference to the accompanying drawing wherein like reference numerals refer to like elements in the various figures and in which:

FIG. 1 is a schematic view of a transformer for use in the present invention;

FIG. 2 is a schematic showing of a first embodiment of a voltage regulator in accordance with the present invention;

FIG. 3 is a graph which depicts the power savings realized through use of the present invention;

FIG. 4 is a schematic showing of a second embodiment of a voltage regulator in accordance with the present invention; and

FIG. 5 is a waveform diagram depicting the unfiltered output voltage obtained from the embodiment of FIG. 4 under the condition of nominal input voltage.

DESCRIPTION OF THE PREFERRED EMBODIMENT

With reference now to FIG. 1, a three-leg transformer core is indicated at 10. The core 10 has, wound on the center leg thereof, a primary winding 12. A first of the outer legs of the transformer core has a single, center-tapped secondary winding 14 wound thereon. The other outer transformer core leg has three separate secondary windings wound thereon. These secondary windings are respectively indicated at 16, 18 and 20. The winding 20 is center tapped.

The manner of interconnection of the secondary windings wound on the transformer core 10 and the operation of the present invention may be understood from a consideration of FIG. 2. The secondary winding 20, which comprises a first secondary winding system will have its center tap directly connected to one side of a load while the opposite ends of the winding 20 will be connected, via a pair of similarly poled diodes 22 and 24, to the other side of the load. The secondary windings 16 and 18 are connected to respective ends of the center-tapped secondary winding 14 and the other ends of windings 16 and 18 are coupled, via a pair of respective, similarly poled diodes 26 and 28, to the input of a series regulator, indicated generally at 30. The center tap of the secondary winding 14 is connected to the same side of the load as the center tap of secondary winding 20. The interconnected windings 14, 16 and 18 form the second secondary winding system.

The series regulator 30 comprises a variable resistance element 32 connected between the series connected secondary windings 14, 16 and 18 and load. The series regulator 30 will also comprise control circuitry 34, which is state-of-the-art and does not comprise part of the present invention, which varies the resistance of element 32, in a manner well-known in the art, in accordance with sensed variations in the line voltage applied to the transformer primary winding 12. The control circuitry 34 may, for example, comprise a differential amplifier which senses discrepancies between the actual output voltage and a reference source. Error signals from the differential amplifier may be employed, in a known manner, to cause the resistance of power handling element 32 to vary so as to achieve the desired output voltage. While element 32 has been shown as a variable resistor, it is to be understood that the power handling element will actually comprise a transistor or FET. In the case of the embodiment of FIG. 4, the output of the differential amplifier would be used to vary the duration of the open and closed periods of switch 40. Control systems of the type which can be used with the present invention are described in general in Chapter 8 of the "Handbook of Selected Semiconductor Circuits," U.S. Government Printing Office publication No. NObsr 73231, NAVSHIPS 93484, 1960. Control circuits particularly suited for use with the embodiment of FIG. 2 of the present invention are discussed at pages 8—16 through 8—19, 8—38 and 8—41 of the "Handbook" while circuits particularly suited for the FIG. 4 embodiment are discussed at pages 8—21 through 8—25 and 8—63.

As will be obvious to those skilled in the art, the flux distribution through the outer legs of the transformer core 10 may be varied by varying the resistance of element 32. Restated, the distribution of the flux generated by current flow in the primary winding 12 is effected by the load current drawn from each of the secondary windings and the load current drawn from the winding 14 will, as will be obvious from FIG. 2, be controlled by varying the resistance of the element 32. Since the voltage induced in the two secondary winding systems is commensurate with flux distribution in the transformer core legs, the load voltage will accordingly also be a function of the flux distribution. By proper selection of the turns ratios of the several secondary windings, the desired load voltage may be made equal to the voltage induced in series connected windings 14, 16 and 18 at the nominal source voltage level. At this time there will be maximum power dissipated in the element 32, and the voltage induced in the winding 20 will be less than that induced in series connected windings 14, 16 and 18. It is to be noted that load current will nevertheless be supplied by the winding 20 under the above-described conditions and thus, since the series connected resistance element will not have the entire load current flowing therethrough, the present invention offers decided economic advantages over prior art series regulators of like character.

Considering the operating extremes, that is with the source voltage at its minimum or maximum expected levels, operating under the influence of the control 34, the variable resistance element 32 will be adjusted to either extreme of its operating range thus presenting, in the case of minimum source voltage, essentially a short circuit and, in the case of maximum source voltage, essentially an open circuit. In the case of the open circuit, again through proper selection of the number of turns on the winding 20, this winding 20 will supply the desired load voltage at the maximum input voltage, there being no load current drawn from the winding 14 at this time and virtually all flux in the transformer core being shunted through the core leg on which windings 16, 18 and 20 are wound. In the case of the shorted regulator element, the load currents drawn from the secondary windings will be distributed so as to produce equal MMF drops in the secondary legs. Under these conditions, the output voltages as induced in the secondary winding systems will be equal. The above-described conditions are depicted graphically in FIG. 4 wherein the power drain in accordance with the present invention is shown by the broken line whereas the power drain attributable to conventional prior art series regulator is shown by the solid line.

Turning now to a consideration of the embodiment shown in FIG. 4, it is to be noted that a conventional switching regulator achieves a constant output voltage level by varying the duty cycle of the switching element thereby coupling the source to the load with infinite or zero attenuation. In accordance with the present invention, the embodiment of FIG. 3 achieves coupling of the unregulated source to the load with a nominal transfer function; the regulation system modifying the transfer function in accordance with the source voltage. It is to be noted that the embodiment of FIG. 4 differs from that of FIG. 2 principally in that the regulating element, a switch 40 and its control circuitry 42, does not have an intermediate position. Thus, the series regulator element of the FIG. 4 embodiment has only the open and short circuited conditions and operation intermediate these extremes is achieved by varying the duty cycle of the switch 40 rather than by increasing the level of power dissipation in the series element. It is also to be noted that, as a result of the modification of the interconnection between the windings in the two secondary winding systems, the embodiment of FIG. 4 employs a pair of additional diodes 44 and 46. Also, since there will be switching transients and ripple generated through the operation of the switch 40, albeit to a lesser degree than in the prior art for the reasons to be described below, a filter comprising a series inductor 48 and a capacitor 50 is also employed in the FIG. 4 embodiment.

The operation of the embodiment of FIG. 4 may be understood by consideration of the application of an input voltage to the primary winding of the transformer, the primary winding 12 having been omitted from FIG. 4 in the interest of clarity, from an unregulated square wave source. With the switch 40 in the open condition, no-load current will be drawn through secondary windings 16 and 18 and transformer core flux distribution will be such that equal voltages are induced in the windings 14 and 20. These equal voltages may be considered to be the desired load voltage at the maximum level of the square wave input. At the other extreme, with the switch 40 closed and load current being drawn through the windings 16 and 18, the core flux distribution will be such that the voltage induced in the winding 20 will be equal to the combined voltages induced in series connected windings 14, 16 and 18. This condition is commensurate with the minimum expected input voltage level and results in the same output voltage as achieved with maximum input voltage and the switch 40 opened.

At intermediate levels of the source voltage, the switch 40 will be operated during each cycle of the source voltage to, in effect, add a synchronized square wave pulse of varying duration, the pulse width with nominal input voltage being one-half of the width of the input square wave, to the voltages induced in the windings 14 and 20. Due to the presence of the diodes 22, 24, 26, 28, 44 and 46, a DC voltage with a ripple as shown in FIG. 5 will be applied at the input to the series inductor 48. The load voltage will, accordingly, be the average of the signal as shown in FIG. 5. It is especially to be noted that the conventional prior art switching regulator produces a much higher level of ripple since it causes the transformer output voltage to vary from zero to maximum rather than over the limited range of the hybrid switching regulator of the present invention. It is also to be noted that, since the input to the filter comprised of the inductor 48 and capacitor 50 will essentially be DC at both extremes of the source voltage magnitude range and will not decrease to zero at any point, filter requirements are simplified and a highly efficient regulator device results. In this regard, it is to be noted that the *L-C* filter shown in FIG. 3 is intended as an example only.

While a preferred embodiment has been shown and described, various modifications and substitutions may be added thereto without departing from the spirit and scope of the present invention. For example, the same magnetic circuit could be used as an AC power controller, using a variable DC load, drawing current from a rectified output, to modulate the level of an AC output. Such a device would find application as an alternative to the conventional variable autotransformer (VARIAC) in applications where its limitations are significant disadvantages.

I claim:

1. A voltage regulation apparatus comprising:

transformer core means, said transformer core means comprising a three-leg, two-window transformer core and including at least two parallel magnetic circuits;

an input winding coupled to said core means and adapted to be connected across an unregulated source of alternating current, said input winding comprising a primary winding wound on a first leg of said core;

a plurality of output windings, said output windings being coupled to preselected of said magnetic circuits whereby voltages may be inducted therein;

flux distribution control means interconnecting certain of said output windings, said control means varying the flux distribution between said parallel magnetic circuits whereby the voltages induced in said output windings will vary;

means for connecting said interconnected output windings across a load, said output windings comprising a first secondary winding wound on a second leg of said core;

a second secondary winding wound on the third leg of said core;

a third secondary winding wound on the third leg of said core; and

a fourth secondary winding wound on the third leg of said core.

2. The apparatus of claim 1 wherein said flux distribution control means comprises means connecting said first, third and fourth secondary windings in series; and variable resistance means connecting said series connected windings to said second secondary windings.

3. The apparatus of claim 2 wherein said variable resistance means comprises switch means connected between one end of said second secondary winding and one end of said series connected secondary windings.