United States Patent [19]

Hoffman

[11] **3,778,699**

[45] **Dec. 11, 1973**

[54] **RESONANT TYPE CURRENT REGULATOR PROVIDING A CONTINUOUS REGULATION**

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[22] Filed: **Aug. 16, 1972**

[21] Appl. No.: **281,256**

[30] **Foreign Application Priority Data**

May 19, 1972 Belgium 117683

[52] **U.S. Cl.** .... **323/6,** 315/239, 315/274, 315/276, 323/44 R, 323/45, 323/60

[51] **Int. Cl.** **G05f 1/30,** H05b 37/02

[58] **Field of Search** .... 315/239, 241 R, 242, 315/243, 244, 274, 275, 276, 283; 323/4, 6, 43.5 S, 44 R, 45, 57, 60

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Primary Examiner—A. D. Pellinen
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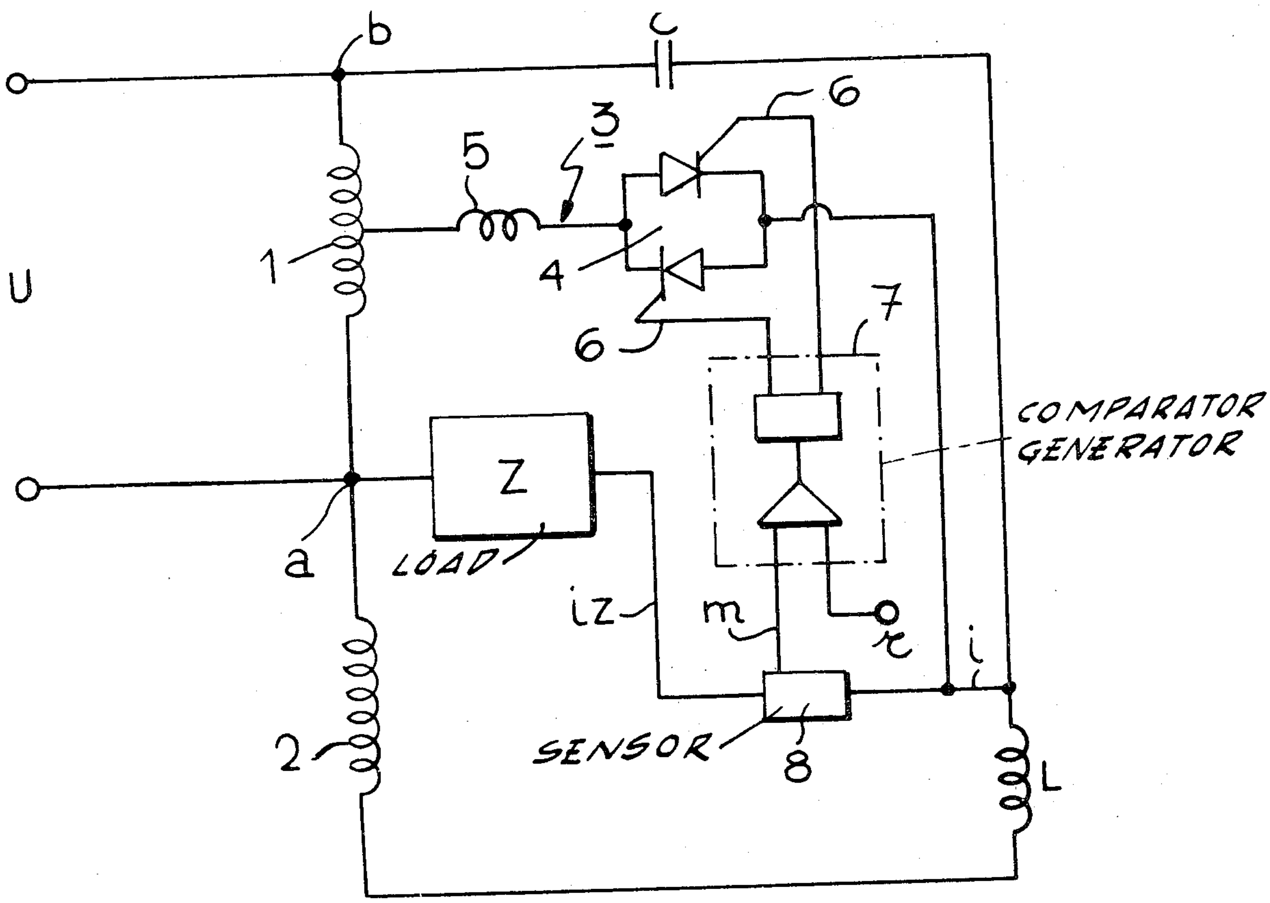
[57] **ABSTRACT**

A resonant type current regulator in which a controlled inductive impedance is provided in series or in shunt connection with the current path. A control is provided to vary the impedance value of the inductive impedance in response to the load current deviating from a reference value in a manner to stabilize the load current. An antiparallel arrangement of a pair of controlled semiconductor devices can be used for the controlled inductive impedance their control gates receiving control signals at times in each current half period which depend on the magnitude of the current deviation.

4 Claims, 4 Drawing Figures



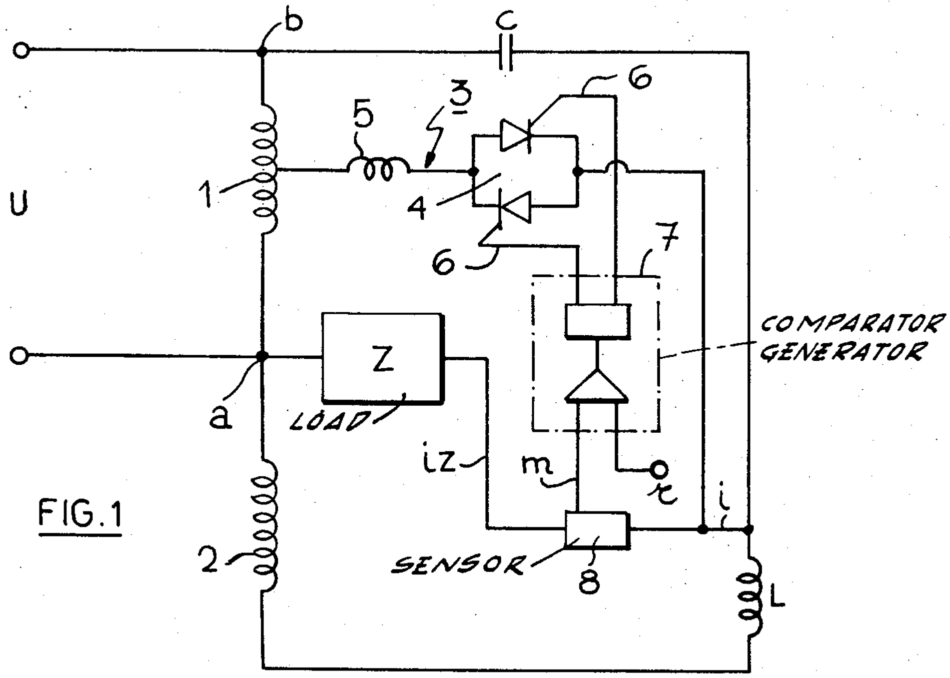

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FIG.1

FIG.2

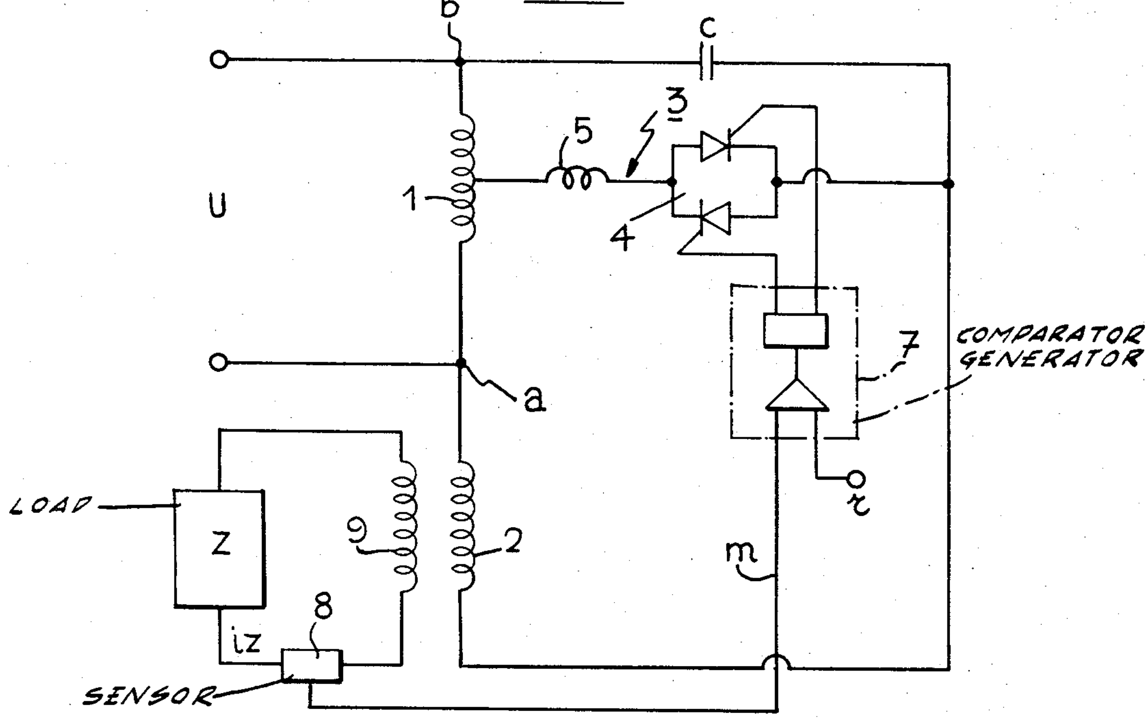
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FIG. 3

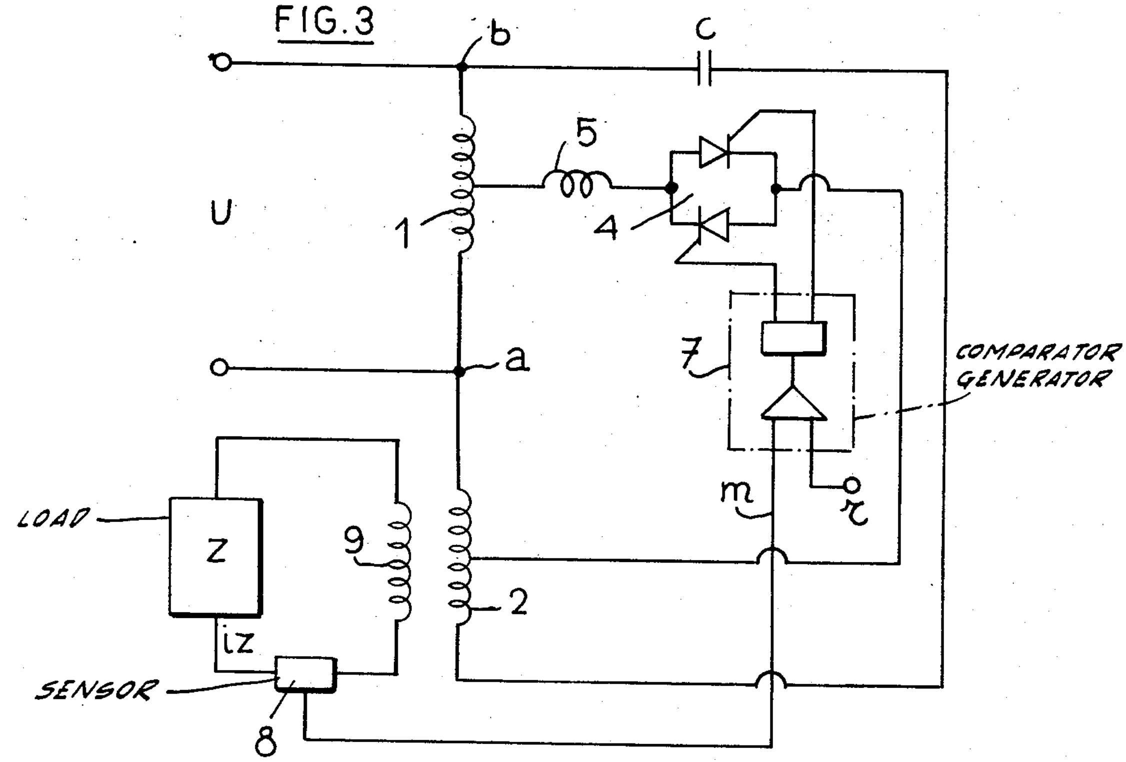
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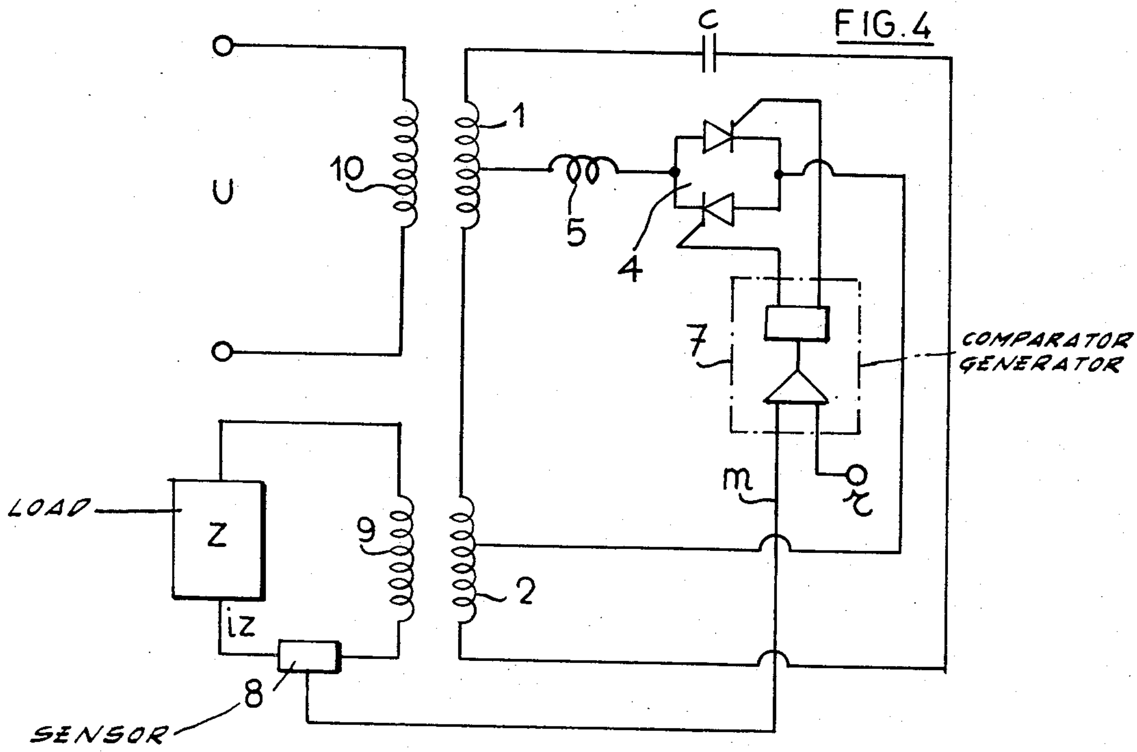
FIG. 4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RESONANT TYPE CURRENT REGULATOR PROVIDING A CONTINUOUS REGULATION

This invention relates to a resonant type current regulator capable of achieving non-interrupted continuous regulation.

To regulate the current flowing through switchable loads such as light beacon devices, use is commonly made of resonant type current regulators which exhibit substantial advantages over the other types of known current regulators.

The resonant type regulators substantially comprise a resonant circuit connected across the load impedance. It is known that if the resonant circuit elements are chosen such that $\omega^2LC=1$ (ω is the angular frequency of the applied voltage) the current i_Z through the load is independent of its impedance since it is related to the applied voltage E by the relationship $i_Z=E/\omega L$.

This type of regulator is satisfactory as regards its operating speed since the current recovers its normal value within the current half period after occurrence of a sudden change of the load. The resonant type regulator also is relatively light in weight and inexpensive as compared to other known types of regulators. However, just like the latters the prior art resonant type regulators have several drawbacks.

Firstly, the current through the load impedance is proportional to the applied voltage. Accordingly, in beacon appliances for instances, loss of brightness may occur when the supply voltage decreases. On the other hand, when the supply voltage increases, the lifetime of lamps is reduced. In addition, the root mean square current can increase to a dangerous extent in some cases, e.g., by breakdown of a number of lamps. To obviate this danger which is due to the presence of harmonics in the lamp transformers with open secondary winding, it is necessary to commonly use harmonic filters which obviously are expensive. In some applications, such as in airport beacon appliances, the maximum value of the rms current is fixed. Lastly, brightness control dictates to provide voltage taps and expensive switching devices for selecting the proper value of the load current.

The foregoing problems are solved in accordance with the invention which provides a resonant type current regulator capable of achieving non-interrupted regulation with recovery of the normal current value within the current half period. An advantageous feature of this invention is that the rms current in any event cannot significantly transiently exceed the nominal current value. Another feature of the regulator is a good power factor even with reduced resistive load. Furthermore, the invention avoids the need for the usual voltage taps and switches for the brightness control.

According to the invention, there is provided controlled inductive impedance means whose impedance value is varied from one value to another in response to a signal indicative of the deviation of the load current from a predetermined reference value, in such a manner as to stabilize the load current. Said controlled inductive impedance may be connected in different ways : in the resonant loop or alternatively in the mains circuitry at the primary side of the transformer. The controlled inductive impedance is advantageously comprised of an antiparallel arrangement of two controlled semiconductor devices, the control gates of which having applied thereto control signals at times in each half period which depends on the magnitude of said current deviation.

In an illustrative embodiment of the invention, the controlled inductive impedance is in shunt connection with the current path. It may be connected for instance between a tap on the transformer winding that is coupled to the supply voltage input and a tap on the winding that is coupled with the load. The impedance is arranged such that it is controlled by a signal indicative of the deviation of the load current from a predetermined reference value, thereby deriving the current differential in a manner stabilizing the load current.

The invention will be more fully understood by reference to the appended drawings wherein :

FIG. 1 is an equivalent circuit of a resonant type current regulator embodying the invention;

FIG. 2 is a simplified schematic drawing of an illustrative embodiment of the regulator of the invention;

FIG. 3 is a simplified schematic drawing of an alternative embodiment of the arrangement of FIG. 2;

FIG. 4 is a simplified schematic drawing of a variation of the embodiment of FIG. 3.

Referring to FIG. 1 there is shown the equivalent circuit of a resonant type current regulator embodying the invention. The regulator depicted comprises an autotransformer comprised of windings 1 and 2 having therebetween a leakage inductance symbolically represented by inductance L. Winding 1 has supply voltage U applied thereto. The load Z is connected across winding 2. Capacitor C forms a resonant loop with said leakage inductance.

In accordance with the invention there is provided a controlled inductive impedance for stabilizing the load current in response to a signal indicative of the load current deviating from a predetermined value. A control means is provided for the inductive impedance, the control means being responsive to the output from a comparison means wherein the load current is compared with a reference value.

In an illustrative embodiment the controlled inductive impedance 3 is connected between the load terminal which is connected to capacitor C and a tap on winding 1. The controlled inductive impedance may, be way of example, be comprised of a conventional antiparallel arrangement 4 of two silicon controlled rectifiers in series connection with a limitation inductance 5. Such an arrangement may in effect be thought of as an inductive impedance since the current flowing therethrough when the SCR's are driven into conduction always lags the applied voltage. Control gates 6 of the SCR's are each connected to a respective output of a suitable deviation detector 7 one input of which is connected to a suitable current measuring means 8, known per se, adapted to produce a signal *m* indicative of load current i_Z. The second input of detector 7 receives a reference signal *r* that may be generated by an external source or by a built-in generator (not shown). Deviation detector 7 which is represented by the conventional representation of the differential amplifier followed by an ancillary circuit may comprise any circuit arrangement as will be readily apparent by those skilled in the art for producing control signals at defined times in each half period which are indicative of the sensed deviation between signal *m* and reference signal *r*.

By controlling their gating instants, the SCR's 4 are made to conduct for all the longer time within each half period as the load current i_Z deviates by more from reference value r. At that time, impedance 3 shunts load Z and derives the current difference in order to restore the load current to its nominal value. It should be pointed out that the current through impedance 3 is an inductive current, that is a current which lags the voltage, and the total current i delivered by the resonant loop always remains constant.

It has been found that selecting the connection point of impedance 3 on winding 1 in accordance with the invention permits the determination of the magnitude and sign of phase angle ϕ (i.e., the phase angle between the sinusoidal supply voltage and the fundamental component of the current derived from the supply means by the regulator). If the connection point is at a, for instance, cosϕ will be capacitive; if at b, cosϕ will be inductive. By varying the connection point along winding 1, the magnitude of cosϕ can be made to vary over a range of capacitive and inductive values. Choosing the particular tap on winding 1 for the connection thus enables the optimal cosϕ to be selected. The regulator of the invention thus provides a good cosϕ (very near to unity) for the whole range of delivered currents, even at reduced load.

Since the total current furnished by the resonant loop has a well defined value, the current through the load can never be transiently excessive of its nominal value, regardless of how slow the regulation loop may act on the value of impedance 3. By contrast, the load current can rise up to several times its nominal value in the other tupes of known current regulators.

The magnitude of the load current can be adjusted very easily by adjusting the value of reference signal r. It will be appreciated how great is the advantage that results therefrom since this control which permits the beacon brightness to be adjusted can be controlled in an auxiliary circuitry. The expensive usual voltage taps and switches can thus be omitted. Brightness control can be made continuously, non-interruptedly by fixed steps, or non-interruptedly by individually adjustable fixed steps.

Regarding the SCR's themselves, it should be pointed out that there is no risk to have them overloaded since they are only conducting excess current and nowise a current which is substantially greater than the nominal load current i_Z. Furthermore, the SCR's only have a relatively low voltage applied thereto. Accordingly there is no need to oversize them as is usual in other types of circuitry. The voltage is an important aspect in regulators intended to be used with high mains voltage such as 2,400V for instance.

Obviously, besides its own features and advantages as discussed above, the resonant type current regulator of the invention exhibits the usual inherent features of the resonant type current regulator, viz. the rapid recovery of the nominal current value within the current half period, for instance after short-circuiting of whole or part of the load.

It will be apparent to those skilled in the art that the equivalent circuit described above may be practiced in different embodiments. FIG. 2 illustrates a typical example wherein the load Z is connected across secondary winding 9 which is tightly coupled with winding 2. This method of connecting the load is quite equivalent to that shown in FIG. 1, as is well known in the art. The leakage inductance, symbolically represented by inductance L in FIG. 1, may be practically in the form of a loose coupling between windings 1 and 2 or a magnetic shunt therebetween.

FIG. 3 illustrates an alternative embodiment for the arrangement of FIG. 2. Inductive impedance 3 is connected between an intermediate tap on winding 1 and an intermediate tap on winding 2. From the standpoint of the equivalent circuit, this arrangement is quite equivalent to that of FIG. 2, but it has the additional advantage that the SCR's have applied thereto a part only of the voltage that is applied to them in the arrangement of FIG. 2. This alternative can be useful in those appliances, e.g., beacon appliances, where the voltage across some apparatus should be limited.

As shown in FIG. 4, an alternative to FIG. 1 may employ a separate primary transformer winding 10 which provides isolation to the secondary winding 1. This is then tightly coupled to winding 10. The circuit otherwise operates as described above in connection with FIG. 3.

The exemplary embodiments described in the foregoing only are illustrative of the principles of the invention. It will be apparent that several variations and modifications can be devised by those skilled in the art. In particular, the controlled inductive impedance can be connected in series with the current path of the load. Further, the controlled inductive impedance can also be connected at the mains side of the regulator circuitry, either in series or in shunt. Furthermore, the arrangement of the invention can be used in other resonant type current regulators by providing a controlled inductive impedance associated therewith, the impedance magnitude of which is related to the deviation between the load current and a predetermined reference value in order to stabilize the load current whatever the applied voltage may be.

What is claimed is:

1. A resonant type current regulator comprising:

input winding means having terminals for connection to an alternating supply voltage,

resonant circuit magnetically coupled to said input winding means with a leakage inductance therebetween, said circuit being arranged to provide a current substantially proportional to the supply voltage,

load means coupled to the resonant circuit for energization thereby at a current which is independent of the impedance of said load means,

sensing means coupled to said load means and adapted to sense the value of the current through the load to provide a first signal representing said current value,

comparing means coupled to said sensing means to compare said first signal from said sensing means with a reference value and provide a second signal representing the deviation of the load current from said reference value,

controlled inductive impedance means connected in shunt with said load means, and

control means responsive to said second signal from the comparing means for varying the impedance value of said controlled inductive impedance means thereby to vary the shunted portion of the current provided by the resonant circuit such that the current through the load is maintained at a substantially predetermined value independent of supply voltage or load impedance variations.

2. A device as set forth in claim **1**, wherein the controlled inductive impedance means comprises a parallel arrangement of oppositely poled controlled semiconductor devices, the control gates thereof being connected to two outputs of said control means such that said controlled semiconductor devices are made to conduct for a longer time interval within each half period of the current as the magnitude of the load current deviates increasingly from said reference value.

3. A resonant type current regulator comprising:

a transformer having a first winding connectable to an alternating supply voltage and a second winding coupled to the first winding with a leakage inductance therebetween.

a capacitor serially connected with said second winding, said capacitor together with said leakage inductance forming a resonant circuit, said resonant circuit providing a current substantially proportional to said supply voltage,

load means coupled to said second winding,

sensing means coupled to said load means and adapted to sense the value of the current through said load means and provide a signal representing the value of said current,

comparison means coupled to said sensing means for comparing the signal from said sensing means with a reference value to provide a signal representing the deviation of said load current from said reference value,

controlled inductive impedance means connected between a tap on said first winding and a tap on said second winding, and

control means coupled to said comparing means and responsive to said deviation signal from said comparing means for providing control signals, said controlled inductive impedance responsive to said control signals for varying the impedance of said controlled inductive impedance, the shunted portion of the current provided by the resonant circuit also varying thereby such that the current through said load is maintained at a substantially predetermined value.

4. A device as set forth in claim **3**, wherein the controlled inductive means comprises a parallel arrangement of oppositely poled controlled semiconductor devices, the control gates thereof being connected to two outputs of said control means such that said controlled semiconductor devices are made to conduct for a longer time interval within each half period of the current as the magnitude of the load current deviates increasingly from said reference value.

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