

United States Patent

Wanlass

[15] 3,683,269

[45] Aug. 8, 1972

[54] **PARAMETRIC VOLTAGE REGULATOR
WITH HIGH POWER TRANSFER
CAPACITY**

[72] Inventor: **Sylvan D. Wanlass**, Santa Ana,
Calif.

[73] Assignee: **Wanless Electric Company**, Santa
Ana, Calif.

[22] Filed: **Aug. 7, 1963**

[21] Appl. No.: **750,914**

[52] U.S. Cl. **323/44 R, 323/60**

[51] Int. Cl. **G05f 3/06**

[58] Field of Search. **323/6, 44, 45, 48, 56, 57,
323/60**

[56] **References Cited**

UNITED STATES PATENTS

2,694,177 11/1954 Sola **323/60**

2,706,271 4/1955 Fletcher **323/60 X**

3,112,439 11/1963 Rosin **323/56**
3,286,159 11/1966 Kuba **323/45**
3,403,323 9/1968 Wanlass **323/56**

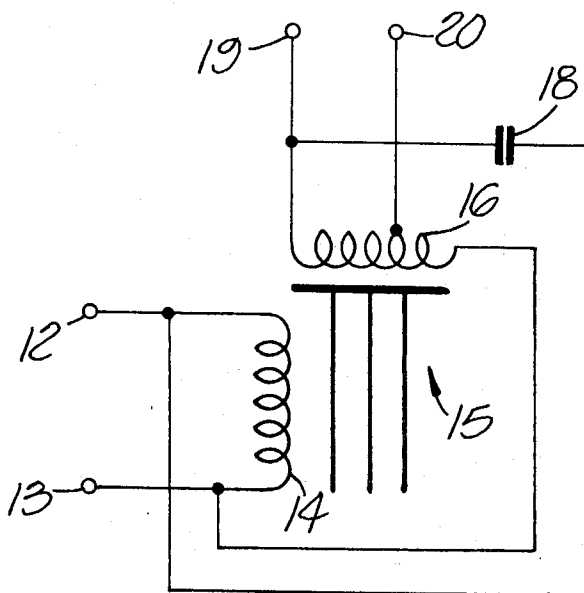
Primary Examiner—A. D. Pellinen

Attorney—Lyon & Lyon

[57] **ABSTRACT**

A voltage regulator in which power is transferred to the resonant circuit of a parametric device by both the parametric mechanism and either flux coupling or direct coupling or both. The device includes a core on which are wound an input winding and at least one output winding which forms part of the resonant circuit. This winding is parametrically coupled to the input winding. Another output winding on the core is connected into the resonant circuit and flux coupled to the input winding, or alternately, the input can be directly coupled into the resonant circuit. In either case, the resonant frequency of the resonant circuit is the same as that of the input voltage.

4 Claims, 3 Drawing Figures



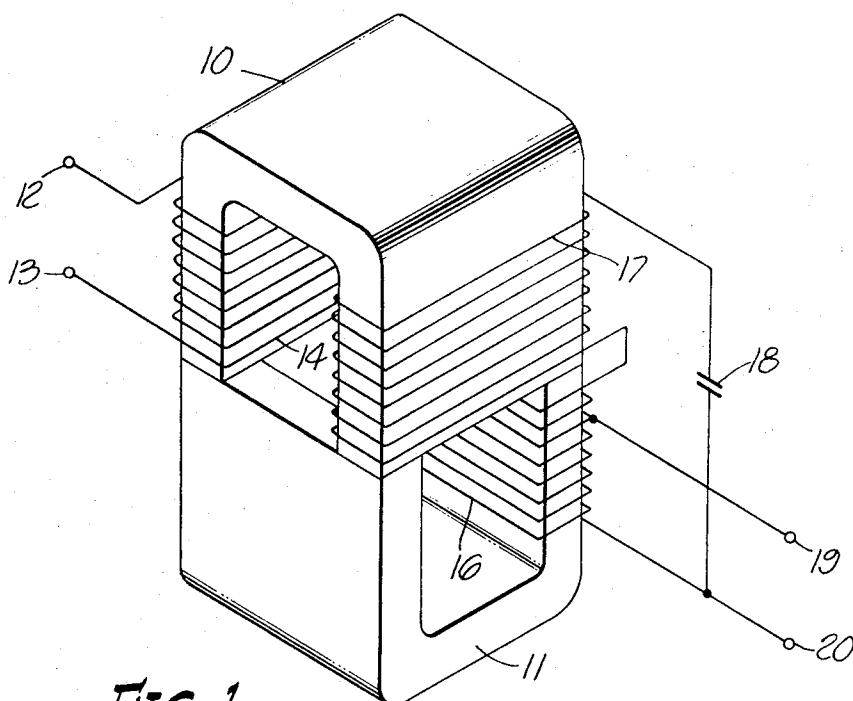


FIG. 1.

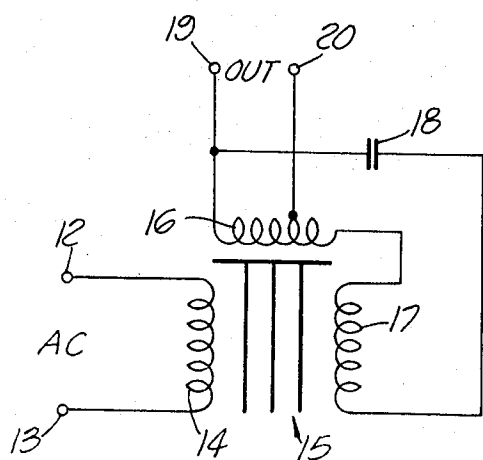


FIG. 2.

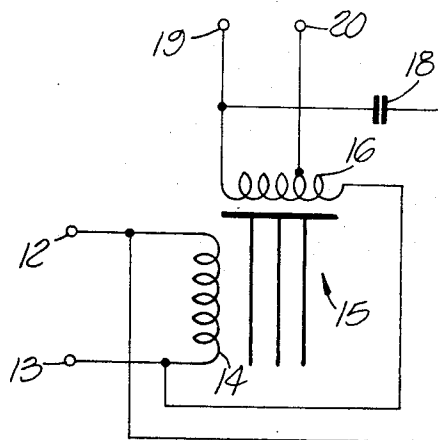


FIG. 3.

INVENTOR
SYLVAN DEAN WANLASS
BY *Lyon & Lyon*
ATTORNEYS

PARAMETRIC VOLTAGE REGULATOR WITH HIGH POWER TRANSFER CAPACITY

BACKGROUND OF THE INVENTION

It has long been desired to provide regulated voltages at high power levels, for example, power levels associated with transmission lines. It has been proposed that instead of conventional transformers, constant voltage transformers of the so-called Sola type be used so that a more or less regulated voltage would be provided. However, these constant voltage transformers have been found to be unsatisfactory for transferring power of the magnitude required, primarily because of their relatively low efficiency and the resultant problem of heat dissipation.

In U.S. Pat. application Ser. No. 589,780 filed Oct. 25, 1966 by Leslie Kent Wanlass and assigned to the assignee of the present application, there is disclosed a voltage regulator employing a parametric circuit for providing a regulated output voltage from an unregulated AC input voltage. The parametric circuit in that application comprises an L-C circuit, the inductance component of which is a variable inductor device of the type disclosed in U.S. Pat. No. 3,403,323 and also assigned to the assignee of the present invention. The theoretical considerations and operating principles of this variable inductor and of the parametric circuit are described in detail in these applications, the disclosures of which are incorporated by reference herein. Briefly, the variable inductor disclosed U.S. Pat. No. 3,403,323 comprises a magnetic core having a pair of windings thereon. The core is constructed so that it has four common regions or "legs" and two end or joining portions for magnetically coupling the common regions. The coils are wound on the end portions with their axes displaced at 90° so that normally there is no mutual inductive coupling between them, and so that the flux components generated as a result of passing currents through the two windings are at all times in opposing relationship in two of the legs and in additive relationship in the other two legs. As a result of this construction, the current in one of the windings, referred to as the control winding, generates a magnetic flux which controls the reluctance of the magnetic circuit encompassed by the second winding, referred to as the load winding, in such a manner that variations in this flux caused by variations in the current in the control winding cause the hysteresis loop of the magnetic circuit encompassed by the load winding to be effectively rotated thereby varying the inductance of the load winding. Because of the construction of the device, the inductance varies at twice the frequency of an alternating current applied to the control winding.

This phenomenon is utilized in the parametric circuit disclosed in application Ser. No. 589,780. In that application, a capacitor is coupled to the load winding of the variable inductor to form a resonant circuit. Energy is transferred to the resonant circuit by pumping the control winding with an alternating current of the same frequency as that to which the resonant circuit is tuned, that is, the output frequency. Once the parametric circuit builds up to its stable oscillating point, variations in magnitude of the pumping source do not appreciably affect its output. Therefore, by coupling the line to be regulated to the control winding of the inductance device, a regulated, almost perfect sine wave, displaced

90° in phase with the input, can be taken from the resonant circuit. Since there is no direct transformer coupling between the windings, the device serves as a bilateral filter, removing transients and noise generated in either the line or the load.

It has been found that for a given size core, only a certain amount of power can be transferred by the parametric circuit describe in U.S. application Ser. No. 589,780. If the load attempts to draw more power than this maximum amount, the device simply turns itself off and transfers practically no power at all. This, of course, is an advantage as it provides built-in automatic overload protection. Although the limits of the power transferring capacity of such a parametric circuit have not yet been discovered, it appears that, like the Sola device, the problems of efficiency and heat dissipation in very large devices might limit the power transfer capacity.

SUMMARY OF THE INVENTION

According to the present invention, a circuit has been provided which is capable of transferring large amounts of power while regulating the voltage. This is accomplished by providing a circuit in which power transfer is accomplished in two modes by parametric coupling and by flux coupling or direct coupling or a combination of the latter two. It has been found that if the tank circuit of a parametric regulator such as that described in U.S. application Ser. No. 589,780 is expanded to include a winding which is flux coupled to the input winding of the parametric regulator, or is directly coupled to the input, substantially greater amounts of power can be transferred through the device without any appreciable loss in the regulating characteristics of the device. Of course, the bilateral filtering capability of the device is greatly reduced but in many applications, this particular feature is not necessary.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a perspective view of a voltage regulator according to the present invention;

FIG. 2 is a schematic diagram of the voltage regulator of FIG. 1; and

FIG. 3 is a schematic diagram of a modification of the voltage regulator of the present invention.

DESCRIPTION OF THE INVENTION

In the drawings, the convention adopted in the aforementioned applications for indicating a core according to the teachings of U.S. Pat. No. 3,403,323 are followed, that is, such a core is indicated by the use of a T-shaped iron symbol. While any of the various core structures illustrated and described in that application could be used in this invention, the preferred construction is similar to that shown in FIG. 7 of that application, that is, a core made up of two C-cores 10 and 11 rotated 90° from each other and joined at their bases, as shown in FIG. 1.

As shown in FIGS. 1 and 2, an unregulated A.C. input voltage is applied to terminals 12 and 13. The control winding 14 of a variable inductor 15 of the type described is connected across the input terminals 12 and 13. The parametrically coupled load winding 16 of

the inductor is connected in series with a winding 17 which is wound on the core of the inductor such that it is flux coupled to the winding 14 in the manner of a conventional transformer. A capacitor 18 is coupled across the windings 16 and 17 to form a resonant circuit. The resonant circuit 16, 17, 18 is preferably tuned to the frequency of the input voltage. When a sufficient input voltage is applied to the terminals 12 and 13 a regulated output voltage will be provided at the terminals 19 and 20 connected across the winding 16. As shown, these load terminals are connected only across a portion of the winding 16 although the capacitor is connected across the entirety of the windings 16 and 17. This arrangement permits the capacitor 16 to be operated at a higher voltage where it is more efficient while maintaining the voltage across the load at a lower value.

FIG. 3 shows a circuit generally similar to that shown in FIG. 2, the only exception being that the winding 17 is deleted and the tank circuit 16, 18 directly connected to the input terminals 12 and 13. In this case, the winding 16 acts as an autotransformer because the output terminals 19 and 20 are connected across only a portion of it; however, it should be understood that the output terminals could be connected across the whole of winding 16. In the case shown, power is transferred by a combination of flux coupling and direct coupling, together, of course, with parametric coupling. If the output terminals were connected across the whole of winding 16, the power transfer would be substantially a combination of direct coupling and parametric coupling. In either case, the power is coupled into the tank circuit of the parametric device which must be able to store the directly or flux coupled energy as well as the parametrically transferred energy, and thus the nature and size of the core is a factor even if there is little or no flux coupling.

It has been found that a circuit connected in either of the manners described can transfer many times more power than could a simple parametric circuit using the same core. To the best of applicant's present understanding, it appears that the power transferred by direct or flux coupling and by the parametrically coupled winding are somehow interleaved so as to permit them to both use the same iron and thus greatly increase the efficiency of the device. As is known, the voltage induced in a winding, and hence the power transferred to it, can be expressed as:

$$V_2 = L di/dt + i dL/dt$$

where V_2 = voltage induced in winding

L = inductance of winding

i = current in winding

In other words, the power transferred is a function of both the inductance of the winding times the change in the current in the winding with time, and the current in the winding times the change of inductance of the winding with respect to time. The first term of the foregoing equation represents the flux coupling phenomena while the second term represents the parametric coupling phenomena. Rather than utilize one or the other of these terms, as is done, for example, in Sola transformers and in the aforementioned

parametric device, applicant's circuit simultaneously utilizes both terms of the equation; in the case of FIG. 2 by the use of two separate windings and in the case of FIG. 3 by the use of a single winding.

The phase relationship of the output voltage to the input voltage of either circuit is a function of the amounts of in phase and out of phase voltages that are mixed and the output voltage is very closely regulated, and it appears that the parametric coupling phenomena controls the final output of the circuit. On the other hand, since the circuits can transfer many times as much power than could the parametric device standing alone, it appears that the greater portion of the power transfer is probably accomplished by other than parametric coupling. The logical conclusion to be drawn from these factors is that the parametric circuit in some way compensates for variations in the voltage and power transferred to the tank circuit through direct or flux coupling. In other words, it appears that the parametric circuit is in some way akin to a peak power regulator, that is, it adds to or subtracts from the voltage and power levels established by the flux coupled winding or by the direct coupling to maintain the output at a constant voltage. It would appear that the parametric circuit thus provides a reservoir from which additional power can be drawn when necessary or into which excess power can be dumped in order to maintain a regulated output voltage.

Another possible explanation of the operation of the circuits is that the majority of the power is transferred through the parametric circuit, the direct or flux coupling only providing a current in the tank circuit of the parametric device on which the pumping action of the parametric device itself can operate. In the basic parametric circuit, a variation of the current in the control winding causes a corresponding variation in the inductance of the load winding. However, in order for this to result in the development of a voltage and a transfer of power, it is necessary for a current to be present in the load winding. This current is generally initiated as a result of noise or as a result of a deliberate and temporary flux coupling of the control and load windings. Since the current in the load winding on which the varying inductance in the load winding operates is itself dependent on the operation of the device, it might be somehow limited, thus limiting the possible power transfer of which the device is capable. For example, with a regulated output voltage, if the load requires greater power, a larger current would have to be drawn from the tank circuit. This might result in the current in the load winding being reduced to a value so low that the resonant circuit is unable to continue to oscillate. By providing what is essentially an external source of current which can be drawn from by the load when necessary, the oscillations of the resonant circuit of the parametric device will not be damped and thus it can continue to function and regulate the output voltage even when large amounts of power are drawn by the load. It would also appear that the larger current would also be operated on by the changing inductance of the load winding so that greater power transfer could take place between the control winding and the load winding of the parametric device.

The theories expressed above are the best presently available to the applicant. However, it should be un-

derstood that the principles governing the operation of the present invention have not been completely developed and it is possible that other theoretical basis for operation will be discovered. The theories presently discussed are thus not meant in any way to limit the scope of the present invention. 5

As illustrated, the circuit of FIG. 2 uses a separate winding to perform the flux coupling function. It should be understood that the control winding and the separate secondary winding could be replaced by an autotransformer or the like. If desired, the secondary winding could be coupled to the input through a completely separate transformer although this would reduce the savings of iron made possible by the present device. It should also be understood that the various modifications of the input and output circuits shown in the aforementioned U.S. application Ser. No. 589,780 could also be used in connection with the present invention. 10 15

There does not appear to be anything particularly critical about the number of turns provided for the output winding 16 or the secondary winding 17 so long as the winding 16 is provided with sufficient turns to be able to regulate properly. The limiting factor appears to be that the winding 16, that is, the parametrically coupled winding, must be able to transfer enough power to make up for the largest expected swings in the power transferred by the direct or flux coupling. Our experiments thus far indicate that this point is reached when the total power transferred exceeds approximately five times what could be transferred by the parametric circuit alone. 20 25 30

What is claimed is:

1. An electrical system comprising:

an input circuit adapted to be connected to a source of A.C. voltage; 35

a variable inductor comprising a magnetic core, a load winding wound on said core and encompassing a magnetic circuit therein, the effective reluctance of said magnetic circuit controlling the inductance of said load winding, and a control winding wound on said core, said control winding being responsive to current therein for controlling 40 45

the effective reluctance of said magnetic circuit whereby variations in said current vary the inductance of said load winding;

means coupling said control winding to said input circuit;

capacitor means connected to said load winding to form a resonant circuit;

means directly connecting said input circuit to said resonant circuit; and

means for connecting a load across at least a portion of said load winding.

2. An electromagnetic power transfer system comprising an input, an output circuit including a resonant circuit, means parametrically coupling said input to said resonant circuit, and means directly electrically coupling said input to said resonant circuit, including means directly conductively connecting said input and output windings.

3. An electrical system comprising:

an input circuit adapted to be connected to a source of A.C. voltage;

a power transfer device having magnetic core means, input winding means and output winding means wound on said core means, said output winding means being parametrically coupled to said input winding means;

capacitor means connected in a resonant circuit with said output winding means;

means for coupling said input winding means to said input circuit;

means directly coupling said input circuit to said resonant circuit, including means directly conductively connecting the input and output windings, for supplying energy to said resonant circuit; and

means for connecting a load across at least a portion of said output winding means.

4. A method of transferring electrical power from an input circuit to an output circuit comprising transferring substantial amounts of power from said input circuit to said output circuit by both parametric coupling and electrical coupling directly connecting said input circuit with said output circuit.

* * * * *

45

50

55

60

65