United States Patent

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[54] **VOLTAGE-REGULATING DEVICE**
10 Claims, 9 Drawing Figs.

[52] **U.S. Cl.** **323/61,** 323/82, 336/155
[51] **Int. Cl.** **G05f 3/06,** H02p 13/04
[50] **Field of Search** ..... 323/44, 57—61, 82; 336/155, 165, 178

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ABSTRACT: A voltage-regulating transformer having coil connected in series with a condenser to form a resonant circuit at the frequency of the source potential, and a ferromagnetic core having one or more magnetic gaps in the flux path of the coil. In different embodiments, the resonant input circuit utilizes separate condensers coupling the source to opposite ends of the coil, and a shunt capacitor across the coil. In separate embodiments, power is taken from the transformer by connection across the coil and by magnetic coupling through a second coil. The voltage-regulating device has the advantage of producing an output potential substantially more stable than the source potential, an output potential substantially sinusoidal in waveform and an output which collapses on overload to inherently protect the device against overloads.

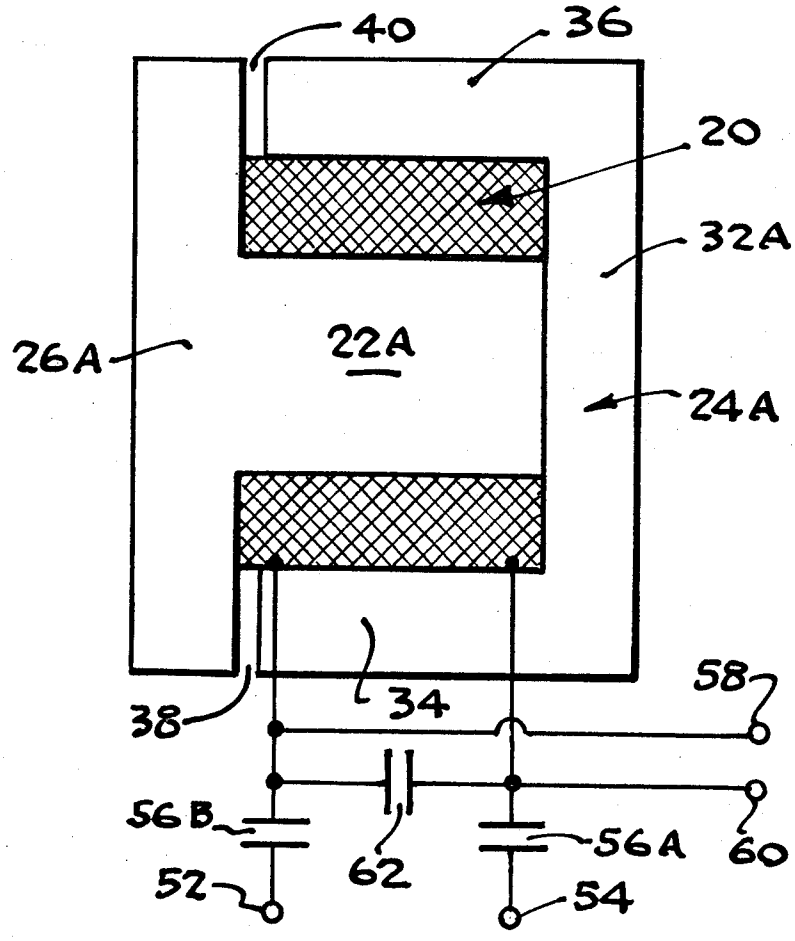


Fig.1

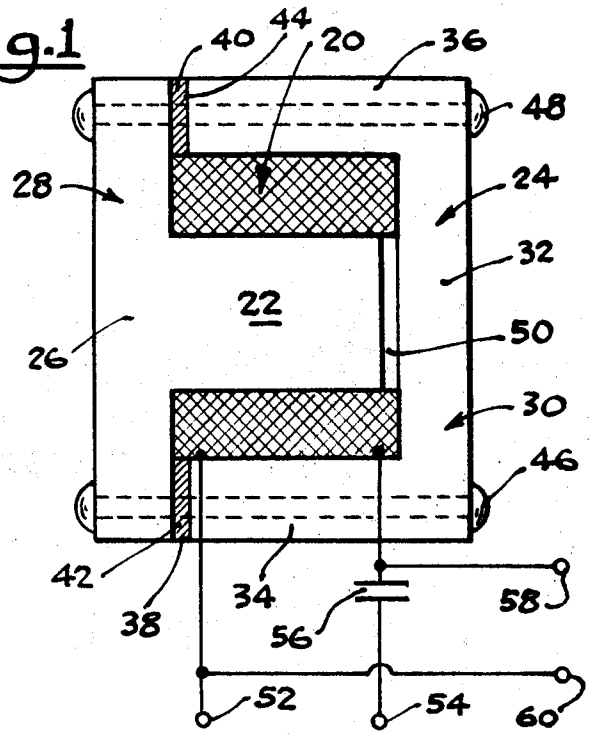


Fig.2

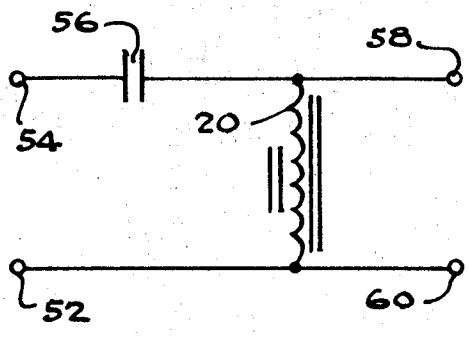


Fig.4

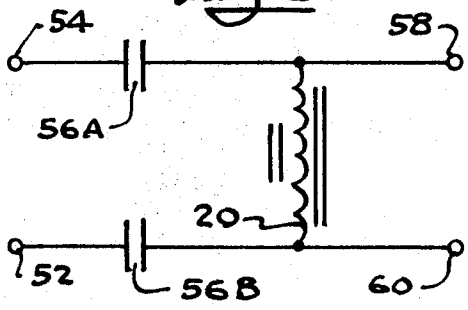
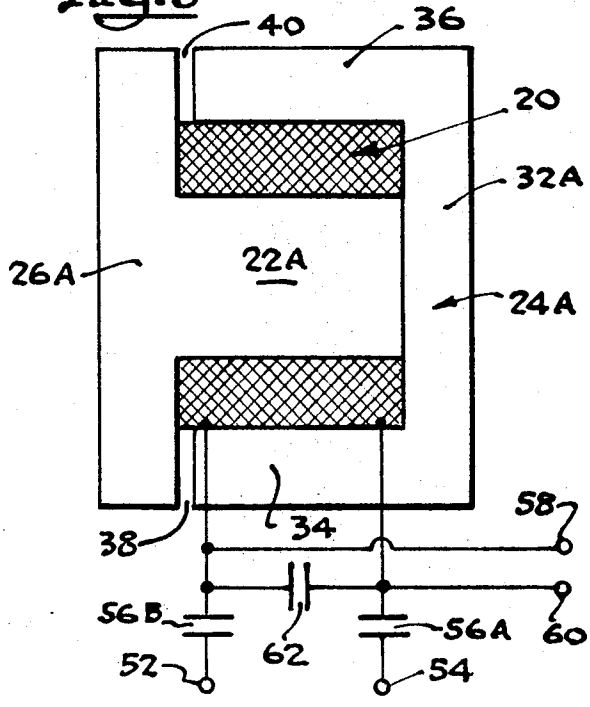


Fig.3



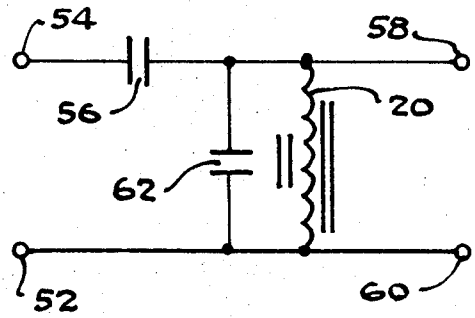


Fig.5

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Fig.6

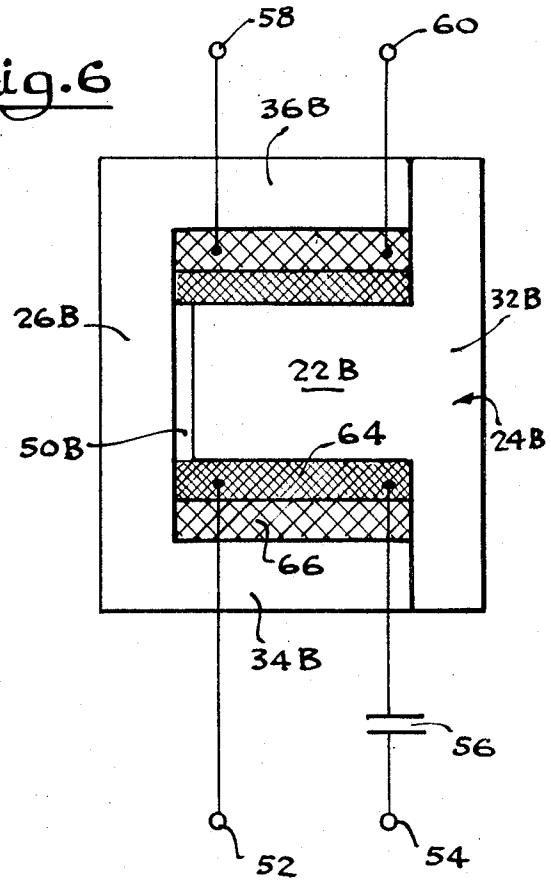
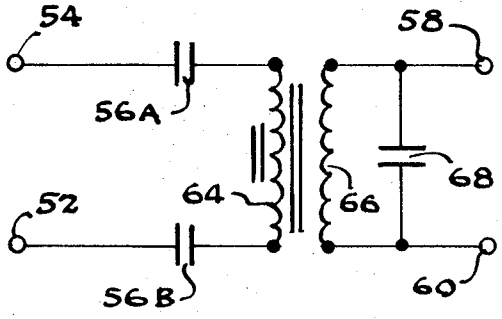


Fig.7



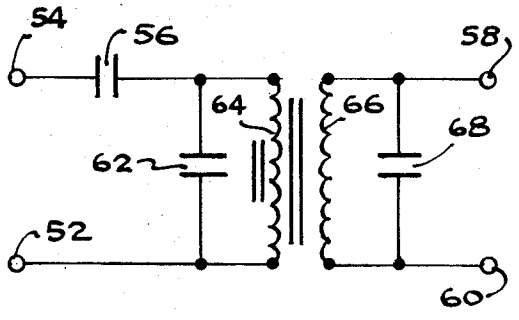
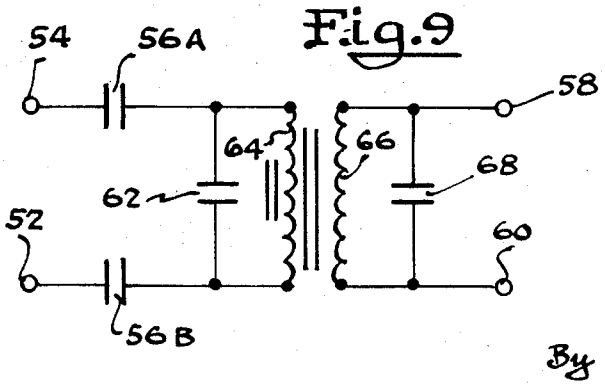


Fig.8

Fig.9



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VOLTAGE-REGULATING DEVICE

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates generally to devices employing transformers for producing a constant potential alternating current output.

2. Description of Prior Art

The present inventor, prior to the present invention, has utilized parallel resonant secondary circuits in a transformer for producing a relatively constant output potential, as disclosed in his U.S. Pat. No. 3,076,136 of Jan. 29, 1963 entitled "Constant Voltage Transformer." Such constant voltage transformers have appeared in a number of different forms, such as that of Mauerer disclosed in U.S. Pat. No. 2,358,725, that of Bridges disclosed in U.S. Pat. No. 2,615,067, that of Sola disclosed in U.S. Pat. Nos. 2,212,198 and 2,806,199, and that of Fletcher disclosed in U.S. Pat. No. 2,706,271.

SUMMARY OF THE INVENTION

The present invention is directed to a voltage-regulating device which utilizes a transformer with a series-resonant circuit employing an inductive and a capacitive component. The transformer also utilizes a ferromagnetic core to provide a low-reluctance flux path for the flux generated by the coil. The low-reluctance flux path is provided with one or more regions of substantially higher reluctance which are utilized to control the magnitude of the flux in the magnetic path. The regions of relatively high reluctance in the magnetic path are in the form of gaps, generally air gaps, and these gaps determine the output potential of the transformer or regulating device. Excessive loading of the regulating device results in the primary of the transformer dropping out of resonance and a substantial decrease in the output potential and delivered power. The present invention has the object of providing a regulated alternating potential output of greater stability than the source potential.

It is also an object of the present invention to provide a regulating device which is self-protecting from overloads or shorts.

It is still a further object of the present invention to provide a voltage-regulating device which will produce an output waveform which is substantially sinusoidal when excited by a sinusoidal waveform source.

Additionally, it is an object of the present invention to provide a voltage-regulating device which is simple to construct and may be constructed less expensively than the voltage-regulating devices presently available.

BRIEF DESCRIPTION OF DRAWINGS

The objects of the present invention and the means of accomplishing these objects will be more clearly understood from a consideration of the drawings, in which:

FIG. 1 is a view of a voltage-regulating device, partly schematic, illustrating the transformer thereof in longitudinal section;

FIG. 2 is a schematic electrical circuit diagram of the voltage-regulating device of FIG. 1;

FIG. 3 is a view illustrating a voltage-regulating device which constitutes another embodiment of the present invention, the transformer being illustrated in longitudinal section and other elements being illustrated schematically;

FIG. 4 is a schematic electrical circuit diagram of still another voltage-regulating device which constitutes a further embodiment of the present invention;

FIG. 5 is a schematic electrical circuit diagram of a modified form of a voltage-regulating device within the scope of the present invention;

FIG. 6 is a view illustrating another voltage-regulating device which constitutes a further embodiment of the present invention, the transformer being shown in longitudinal section and other elements being shown schematically;

FIGS. 7, 8 and 9 are schematic electrical circuit diagrams illustrating modification of the voltage-regulating device illustrated in FIG. 6.

The transformer illustrated in FIG. 1 has a single coil 20 toroidal in form and disposed about a rectangular portion 22 of a ferromagnetic core 24. The rectangular portion 22 extends from a bar portion 26 of a first part 28 of the ferromagnetic core 24. The core 24 has a second part 30 with a U-shaped configuration formed by a central bar 32 and two outwardly extending legs 34 and 36 from opposite ends of the bar 32. The ends of the legs 34 and 36 opposite the bar terminate in spaced confrontation with the bar portion 26 of the first part 28 to form magnetic gaps 38 and 40. In the particular construction illustrated, the magnetic gaps are formed by brass inserts 42 and 44, although it will be recognized that an air gap would serve as well. The first portion 28 of the core 24 is secured to the second portion 30 of the core by means of nonmagnetic rivets 46 and 48, the rivet 46 extending through the leg 34, the brass insert 42, and the bar portion 26, and the rivet 48 extending through the leg 36, brass insert 44 and leg portion 26.

The rectangular portion 22 of the first part 28 terminates at a distance from the bar 32 of the second part 30 of the core, thereby providing an air gap 50. It will thus be recognized that the transformer is provided with three separate magnetic gaps, namely the gaps 38, 40 and 50.

The coil 20 has a single winding which is connected to two input terminals 52 and 54, the input terminal 54 being connected through a capacitor 56. The single winding is also directly connected to two output terminals 58 and 60.

The schematic electrical circuit diagram for the transformer of FIG. 1 is illustrated in FIG. 2. The reference numerals used in FIG. 1 are also shown in FIG. 2 where applicable.

The transformer is intended for service with an alternating current source of a particular frequency connected across the input terminals 52 and 54. The coil 20 and capacitor 56 are selected to form a series tuned inductive capacitive resonant circuit at the frequency of the power source. Under these conditions, the coil 20 and capacitor 56 would theoretically exhibit zero true loss to the input source, but since both of these components have true resistance, they will demand current to overcome the resistive losses. It can be shown that the current through the input circuit, that is, the circuit from the input terminal 52 through the coil 20, capacitor 56 to the terminal 54, is expressed by the equation

$$I=\frac{V}{\sqrt{R^2+\left(2\pi fL-\frac{1}{2\pi fC}\right)^2}}$$

where I is the current flowing through the circuit, V is the potential of the source, R is the resistive component in the circuit, f is the frequency of resonance, L is the inductance of the coil 20, and C is the capacitance of the capacitor 56. It also can be shown that the voltage drop across the resistance in the circuit, V_R, is given by the equation

$$VR=\frac{VR}{\sqrt{R^2+\left(2\pi fL-\frac{1}{2\pi fC}\right)^2}}$$

The voltage drop across the inductance or coil 20, designated V_L, is given by the expression

$$V_L=\frac{VXL}{\sqrt{R^2+\left(2\pi fL-\frac{1}{2\pi fC}\right)^2}}$$

where XL is the impedance of the inductor, or $2\pi fL$. Likewise, the voltage drop across the capacitor, V_C is given by the equation

$$V_C=\frac{VXC}{\sqrt{R^2+\left(2\pi fL-\frac{1}{2\pi fC}\right)^2}}$$

where XC is the impedance of the capacitor, or $\frac{1}{2\pi fC}$. These equations hold true for all types of transformers, and will not in themselves produce a voltage-regulated transformer.

In order to achieve voltage regulation, it is necessary that a ferromagnetic core **24** be used and that loose coupling be achieved between the output terminals **58** and **60** and the input terminals **52, 54**, thereby providing certain relationships which will be described hereafter.

Loose coupling is achieved by providing one or more gaps in the magnetic circuit so that the flux generated by the current flowing through the winding or coil **20** cannot complete a full magnetic path without overcoming and flowing through a gap. The gaps may be air gaps, such as the gap **50** of FIG. **1**, or formed by regions of nonmagnetic material, such as the brass inserts **42** and **44** in the gaps **38** and **40**. The magnetic gaps have three principal effects, namely (1) to limit the total usable magnetic flux for energy transfer, (2) to provide a means of controlling the limits of saturation of the iron core achieved by the current flowing through the winding **20**, and (3) to keep the voltage-energy waveform substantially sinusoidal by preventing the flux density from entering a nonlinear portion of the saturation curve for the iron core material or a flux density which results in high magnetic circuit losses.

At resonance, the voltage which develops across the capacitor **56** is equal to the voltage developed across the inductor **20**, since the reactive component of the inductance is equal to the reactive component of the capacitance at resonance in an inductive-capacitance circuit, neglecting true resistance losses in the circuit. The voltage drop across the capacitor and the voltage drop across the inductance at resonance will always be greater than the source voltage and limited by the ratio of the true circuit losses to the reactive impedance of the circuit elements, assuming the resistive circuit losses to be small compared to the reactive and capacitive components at resonance. For example, in one particular transformer, the inductive reactance and capacitive reactance at resonance was found to be 80 ohms and the resistive component of the order of 15 ohms. With an alternating source of 100 volts AC at 60 cycles and an input current of 2 amperes, the voltage developed across the capacitor and inductance are each approximately 160 volts AC. A regulated and lower voltage may be obtained from the output terminals **58** and **60** by adjusting the air gaps to reduce the flow of magnetic flux resulting from the 2 ampere current flowing through the coil **20**. A regulated voltage of 100 volts AC may be obtained by increasing the air gaps so that the voltage across the coil **20** can never exceed 100 volts AC from a source operating at the resonant frequency of the circuit. An increase in the potential of the source results in a greater potential appearing across the capacitor **56**, but no substantial change in the potential appearing across the coil **20**. Hence, an increase in the potential applied across the terminals **52** and **54** does not result in a significant change across the terminals **58** and **60**.

The maximum load current is determined by the input current less the circuit losses (real or imaginary). Any attempt to exceed this maximum loading results in the circuit dropping out of resonance, and the transformer voltage appearing across the coil **20** (and hence the output terminals **58** and **60**) drops to a value determined by the load resistance presented across the reactive components of the circuit. Simultaneously, the input current through the capacitor **56** and coil **20** will fall to some value also determined by the series impedance presented by these circuit components. If the output terminals **58** and **60** are shorted, the input current true power falls to zero and the reactive current reduces to that value determined by

$$V/R=V/XC$$

As a result, this transformer is self-protecting and requires no fuse.

The regulating transformer of FIG. **1** (1) is provided with an inherent and built-in volt-ampere capacity, since the current input and output to the unit collapses when this capacity is exceeded, (2) is inherently self-protecting, (3) inherently achieves a substantially sinusoidal output voltage substantially free from higher harmonic distortion, (4) inherently isolates the load impedance from the source impedance, (5) inherently suppresses input line surges, and (6) generates a higher or a lower voltage than the source voltage without the need for a step-up or stepdown transformer.

The transformer of FIG. **1** utilizes three gaps to limit the magnetic flux resulting from current flowing through the coil **20**. The same results may be obtained with a single magnetic gap **50** between the cylindrical portion **22** and the bar **32**, the gaps **38** and **40** being eliminated by use of ferromagnetic inserts **42** and **44** or by the direct abutment of the legs **34** and **36** with the bar portion **26** of the first part **28**.

FIG. **3** illustrates a regulated transformer with a slightly different core construction, the core being designated **24A** and being a single unitary unit. The core **24A** has a cylindrical portion **22A** which extends between two end bars **26A** and **32A**, and a pair of legs **34** and **36** extend from the ends of the end bar **32A** toward the bar **26A**. The legs **34** and **36** are spaced from the bar **26A** leaving air gaps **38** and **40**. The coil **20** is disposed about the cylindrical portion **22A**. It should thus be noted that only two gaps are employed, namely the air gaps **38** and **40**. These gaps function in the same manner as the three gaps illustrated in FIG. **1** and for the same purpose.

The capacitor **56** of the voltage-regulating transformer of FIG. **1** must be capable of storing substantial energy since the potential developed across it will be equal to 2 **VL**, where V is the potential of the source and L is the inductance of the coil **20**. In FIG. **3**, two separate capacitors **56A** and **56B** are utilized between the input terminals **52** and **54** and the coil **20** to divide the charge. Each of the capacitors **56A** and **56B** need only store one fourth the charge of the capacitor **56** illustrated in FIG. **1**, other conditions in the circuit being the same. Splitting the capacitance across each path of the transformer divides the voltage across each capacitor by half and reduces the total energy storage requirement by four because the energy stored in the capacitor is proportional to the square of the potential appearing across the capacitor. This circuit is schematically illustrated in FIG. **4**. In addition to dividing the voltage across capacitors **56A** and **56B**, the circuit of FIG. **4** has the added advantage of equalizing the current distribution across the coil **20**, thus improving the waveform and causing it to more closely approach a sine wave.

FIG. **5** is a modification of the circuit of FIGS. **1** and **2**, and the same reference numerals have been used to designate the same elements. The embodiment of FIG. **5** differs from the embodiment of FIGS. **1** and **2** in that capacitor **62** is connected in parallel with the coil **20**. The capacitor **62** reduces the reactive current component flowing through the coil **20**, and hence also has the effect of improving the form of the output wave and causing it more closely to approximate a sine wave. In FIG. **3**, a capacitor **62** is shown connected across the coil **20**, as in the embodiment of FIG. **5**, but the embodiment of FIG. **3** also employs capacitors **56A** and **56B** connected in series with the input to the coil **20**. Hence this construction incorporated the advantages of the embodiments of FIGS. **4** and **5** in achieving a sinusoidal output waveform and in dividing the potential across the two input capacitors **56A** and **56B**.

FIG. **6** illustrates another embodiment of a voltage-regulating device constructed according to the teachings of the present invention. In this embodiment, a core **24B** is utilized which has a cylindrical coil tranversing portion **22B** extending from a bar portion **32B**. The bar portion **32B** is integral with a second bar portion **26B** parallel thereto and spaced therefrom through two leg portions **34B** and **36B**. An air gap **50B** is disposed between an end of the cylindrical portion **22B** and the confronting surface of the bar portion **26B**. The legs **34B** and **36B** and the bar portions **32B** and **26B** form a yoke about the coil traversing portion **22B**.

A primary coil **64** is disposed about the portion **22B**, and a secondary coil **66** is wound about the primary coil **64**. The ends of the primary coil **64** are connected to a pair of input terminals **52** and **54**, the latter being connected through a capacitor **56**. The ends of the secondary coil **66** are connected to the output terminals **58** and **60**.

The voltage-regulating unit of FIG. 6 operates in a manner similar to that of the unit of FIG. 1, except the output terminals 58 and 60 are magnetically coupled through the secondary coil 66 to the primary coil 64 The primary coil 64 is connected in a series resonant circuit with the capacitor 56 at the frequency of the power source.

For many circuits it is desirable to utilize a transformer coupling, both because the potential may be stepped up or stepped down and because there is direct current isolation between the primary and secondary windings. The transformer diagrammatically illustrated in FIG. 4 may also be utilized with a transformer having a primary winding 64 and a secondary winding 66, as illustrated in FIG. 7, identical elements carrying identical reference numerals. Also, the current distribution in the secondary winding 66 of the transformer may be equalized by a capacitor 68 connected in parallel therewith, but the capacitor 68 is not required unless the sinusoidal waveform is very greatly desired.

The embodiment of FIG. 8 corresponds to the embodiment previously described in FIG. 5, except the coil 20 has been replaced by a transformer having a primary winding 64 and a secondary winding 66. The identical elements of the voltage-regulating device of FIG. 8 bear the same reference numerals as used in FIG. 5. In addition, FIG. 8 employs a capacitor 68 in parallel with the secondary winding 66 in the event further improvement in the sinusoidal waveform in the output is desired.

FIG. 9 illustrates a modified construction over that of FIG. 3 in that the coil 20 has been replaced by a transformer employing a primary 64 and a secondary 66. Also capacitor 68 is illustrated and connected in parallel with the secondary winding 66 in the event a close approximation to sinusoidal waveform in the output is desired.

Those skilled in the art will recognize that the present invention may be carried out with other configurations than that here set forth. The ferroresonant input circuit of the voltage-regulating transformer will establish flux densities in the ferromagnetic core which must be controlled by one or more magnetic gaps, either in the locations indicated in the embodiments here set forth or in other locations in the path of the magnetic flux generated by the coil. Hence, the scope of the present invention should not be limited by the foregoing specific embodiments, but rather only by the appended claims.

The invention I claim is:

1. A voltage-regulating device comprising a transformer having a core with a magnetic conductivity at least equal to that of iron, the core having a coil-traversing portion and a yoke extending from the coil-traversing portion, the core forming a magnetic circuit including in series the coil-traversing portion, the yoke and a magnetic gap, a coil disposed about the coil-traversing portion of the core, means to connect the coil to a source of alternating current of a fixed frequency including a capacitor connected in series with the coil and also in series with the source, the coil and capacitor forming a series-resonant circuit at the frequency of the source, and the resistive components of the coil and capacitor at resonance being small compared to the reactive components thereof, and means to couple a load to the voltage of the coil while obviating any coupling to the voltage of the capacitor.

2. A voltage-regulating device comprising the combination of claim 1 wherein the core provides a plurality of magnetic gaps in the magnetic circuit.

3. A voltage-regulating device comprising the combination of claim 1 wherein the coil-traversing portion has an outwardly extending bar portion on one side of the coil, and the yoke is disposed on the opposite side of the coil and has two legs generally parallel to and spaced from the coil-traversing portion of the core and extending toward the bar portion, whereby the magnetic circuits are formed through the coil-traversing portion, bar portion and each of the legs of the yoke.

4. A voltage-regulating device comprising the combination of claim 3 wherein one gap is disposed between the coil-traversing portion of the core and the yoke.

5. A voltage-regulating device comprising the combination of claim 3 wherein one gap is disposed between each leg of the yoke and the bar portion of the core.

6. A voltage-regulating device comprising the combination of claim 1 wherein two capacitors are connected in series with the coil and the source, one capacitor at each end of the coil.

7. A voltage-regulating device comprising the combination of claim 1 in combination with a capacitor connected in shunt with the coil.

8. A voltage-regulating device comprising the combination of claim 1 wherein the means to couple a load to the coil comprises connections to opposite ends of the coil.

9. A voltage-regulating device comprising the combination of claim 1 wherein the means to couple a load to the coil comprises a second coil on the coil-traversing portion of the core and magnetically coupled to said first-mentioned coil.

10. A voltage-regulating device comprising the combination of claim 9 in combination with a capacitor electrically connected in shunt with the second coil.