United States Patent

Chung

[15] **3,681,679**

[45] **Aug. 1, 1972**

[54] **CONSTANT VOLTAGE TRANSFORMER THREE-PHASE FERRO RESONANT**

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[52] **U.S. Cl.** **323/6,** 323/48, 323/61, 336/5, 336/155

[51] **Int. Cl.**.....**G05f 3/06,** G05f 7/00

[58] **Field of Search**.....323/48, 49, 50, 56, 60, 61, 323/6; 336/155, 5, 170

[56] **References Cited**

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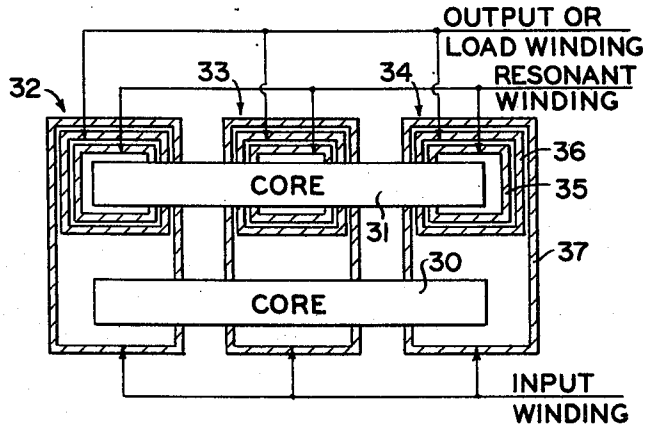
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Primary Examiner—Gerald Goldberg
Attorney—Duckworth & Hobby

[57] **ABSTRACT**

A constant voltage transformer apparatus having two magnetic cores with an input winding linking both cores and an output winding linked to only one of the cores. A resonant circuit is liked to the core having the output winding which core has a flux therein which is the sum of the flux from the input winding and the flux generated by the resonant circuit winding so that this core may be saturated for a constant output in the output winding while the second core is unsaturated and acts to absorb a rise of the input voltage. The symmetry arrangement of the cores and coils makes it especially useful for a multiphase constant voltage transformer. The transformer has an inherent current limiting characteristic and removal of the resonant circuit renders the transformer to be used as a conventional transformer with the added advantage of current limiting.

5 Claims, 5 Drawing Figures



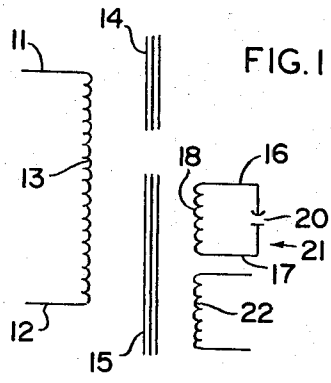


FIG. 1

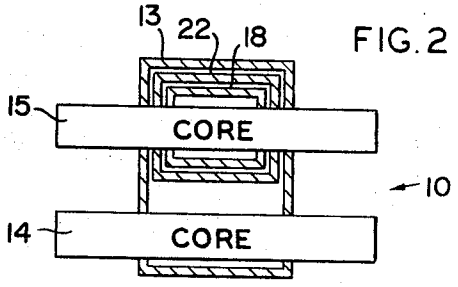


FIG. 2

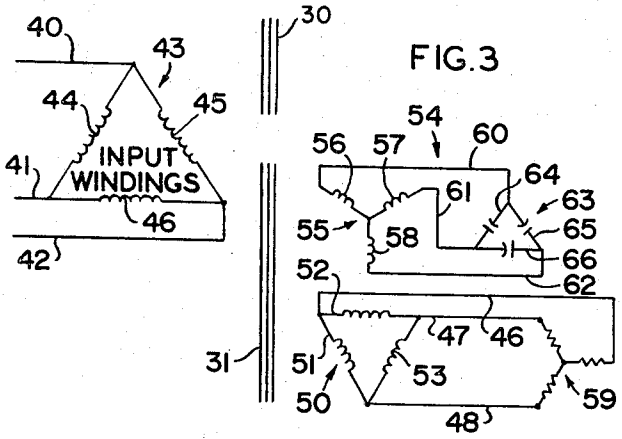


FIG. 3

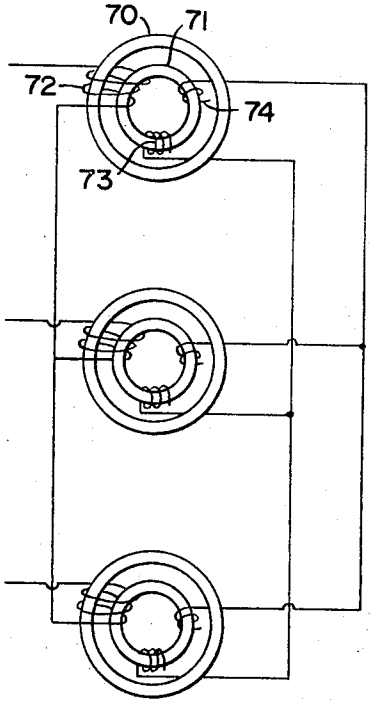


FIG. 5

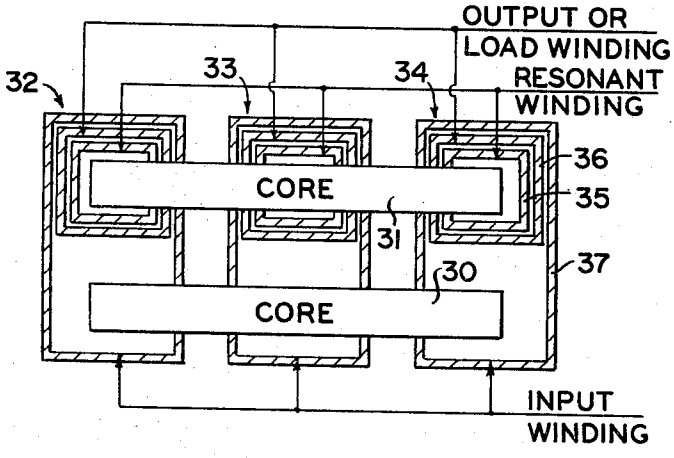


FIG. 4

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CONSTANT VOLTAGE TRANSFORMER THREE-PHASE FERRO RESONANT

BACKGROUND OF THE INVENTION

The present invention relates to ferroresonance type constant voltage transformers, especially to such transformers adapted for multiphase use.

Ferroresonant constant voltage transformers have been common in the past, but have primarily been of the type disclosed in Solar U.S. Pat. No. 2,143,745, which transformer has been both popularly and extensively used in the industry, which transformer has been satisfactory in singlephase use but cannot be built as an individual single unit to work from a multiphase power source, such as a three-phase source where often a high power output may be demanded. It has been used by combining several single-phase transformers of this prior art type operated from a multiphase source such as three-phase output whereby three separate single-phase units are connected to operate from the multiphase source. This, however, results in the disadvantages of only certain or limited types of schemes of multiphase connections that are thereby possible, and the system so formed is susceptible to instability and oscillation. This type of arrangement also becomes expensive and bulky.

It is accordingly one object of the present invention to provide a single unit multiphase ferroresonany constant voltage transformer, without any restriction to the scheme of the multiphase connection that may be desired.

Another Solar U.S. Pat. No. 2,694,177, provides for a ferroresonant transformer providing near perfect sinusoidac output, providing an improvement over the previous constant voltage transformer.

Another prior art patent, U.S. Pat. No. 2,973,470, for voltage regulator provides a voltage regulator utilizing two cores one of which is saturated for all values of load current, while the other core is non-saturated when the load current is 0 and saturated when full load current is being delivered. In this patent the voltage regulator depends upon a variation of a saturable core reactor and parallel with a capacitor to produce resonance or near resonance as a load and the applied voltage are varied.

One object of the present invention is to provide a ferroresonant constant voltage transformer that can be built economically by employing readily available cores and using conventional winding methods.

It is another object of the present invention to provide a ferroresonant constant voltage transformer with an inherent current limiting characteristic should a short develop at the output and which transformer can be used as an ordinary conventional transformer with the added advantage of its inherent current limiting characteristics.

SUMMARY OF THE INVENTION

The present invention relates to ferroresonant constant voltage transformers having first and second magnetic cores with an input winding linking both cores. One core has an output winding linked thereto along with a resonant circuit having a resonany winding and a capacitance. The first core is designed so that a flux therein will be equal to the sum of the primary flux from the input circuit and a secondary flux generated by the resonant circuit so that this core will remain saturated in normal operation and will have the output winding linked thereto for a constant output. The second core, however, will be linked only to the input winding and will not normally be in a saturated condition and will thereby act to absorb the rise of the input voltage when the first core is saturated and act to limit the excessive input current should a short develop at the output. The transformer has a symmetry structure which makes it especially useful in multiphase constant voltage transformer operation.

BRIEF DESCRIPTION OF THE DRAWINGS

Other objects, features and advantages of this invention will be apparent from a study of the written description and the drawings in which:

FIG. **1** shows schematic diagram of the equivalent circuit of a single-phase ferroresonant constant voltage transformer in accordance with the present invention;

FIG. **2** shows a sectional view of a single-phase ferroresonant constant voltage transformer in accordance with the embodiment of FIG. **1**;

FIG. **3** illustrates a schematic diagram of an equivalent three-phase ferroresonant constant voltage transformer in accordance with the present invention;

FIG. **4** is a sectional view illustrating the relationship between the cores and windings of a three-phase ferroresonant constant voltage transformer; and

FIG. **5** is a toroidal core winding arrangement for a three-phase transformer in accordance with the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now to FIGS. **1** and **2** of the drawings, a ferroresonant constant voltage transformer **10** is illustrated for operation in a single-phase mode. An alternating input voltage is applied across a pair of terminals **11** and **12** of an input winding **13** of the transformer **10** which input winding **13** links a pair of cores **14** and **15** applying a flux density

$$B = \frac{E \times 10^8}{4.44fNA}$$

in each core, where E is the applied voltage, f is the frequency, N is the number of turns of input winding, and A is the total core area linked by the total input turns. The excitation or primary flux ϕp can be expressed by $\phi = B \times A$ and at any instant the primary flux existing in core **14** will be found in $\phi 14 = B14 \times A14$ and in core **15** will be $\phi 15 = B15 \times A15$, where:

$\phi 14$ is the flux that exists in core **14**
B14 is the flux density in core **14**
A14 is the cross section area of core **14**
$\phi 15$ is the flux existing in core **15**
B15 is the flux density in core **15**
A15 is the cross section area of core **15**

The transformer action will induce a voltage across terminals **16** and **17** of a resonant winding **18** causing a current to flow in the resonant capacitor **20** resulting in a secondary flux ϕs because of the resonance in the circuit **21** having resonant winding **18** and a capacitance **20**. This secondary flux is derived from a capacitive current which is in time phase with the primary flux ϕp which secondary flux ϕs exists in core **15** only, as

distinguished from the flux generated by the input winding **13** which is in core **14** and **15**. The result is an addition of flux in core **15**. Using Amp's Law, the total flux in core **15** may be expressed to be dependent upon the sum of ampere × turns. Thus, $Np \times Ip + Ns \times Is$ where Np is the number of turns of input winding, Ip is the magnetizing current due to energizing input winding, Ns is the number of turns of resonant winding, and Is is the current in the resonant winding. Hence, at any instant the amount of flux in core **15** is the sum of the primary flux and the secondary flux $\phi p + \phi s$ whereas the flux that exists at any instant in core **14** is only the primary flux ϕp. The selection of the proper combination and correct values for the cores **14** and **15** and the turns on the input winding **13**, turns on the resonant winding **18** and resonant circuit capacitor **20** allows transformer core **15** to reach saturation of its magnetization curve while core **14** is still far from being saturated. The object is to design the transformer in which the core **15** becomes saturated during that portion of the input voltage required for the output voltage to be regulated. For example, if it is desired to have the output regulated from an input voltage of 80 volts to 130 volts, the flux in core **15** should be determined so that core **15** will be saturated at slightly below 80 volts. Further increases of the input voltage from 80 volts on up to 130 volts will produce essentially little or no change in flux in core **15** since it has already become saturated. In the meantime the impedance of core **14** should be as such it will absorb the additional flux in the input voltage rise from 80 to 130 volts in this particular example. An output or load winding **22** links only with the saturated core **15** and has a voltage induced therein whose peak amplitude E may be expressed by

$$E = -4.44 f N A B \times 10^{-8}$$
$$= K(d\phi/dt)$$
$$= \text{constant}$$

since $(d\phi/dt) \rightarrow$ constant

where

f is the frequency

N is the number of turns output winding

A is the cross-section area of core **15**

B is the flux density in core **15**

K is $-4.44 f N A$

Core **14** acts to absorb the rise of the input voltage when core **15** is saturated, and the impedance of core **14** also acts to limit the excessive input current should a short develop at the output and hence the transformer becomes an inherent current limiting device. As can be seen at this point, a single-phase ferroresonant constant voltage transformer has been provided but the concept of the invention provides a symmetry structure which is essential to a multiphase constant voltage transformer, and as can be seen in connection with FIGS. **3** and **4**, a three-phase constant voltage transformer can be easily adapted from the single-phase transformer concept. In actual practice a pair of cores **30** and **31** may be used having three sets of coils or windings **32**, **33** and **34** wrapped thereon, each coil **32**, **33** and **34** will of course be identical with the design of each coil, including the computation of winding turns, core area, and resonant values, based on the analysis of the transformer performing in a single-phase mode as if building three identical single-phase transformers, except that each coil is assembled onto one leg of the three-phase core structure having cores **30** and **31**. Thus, each core has a resonant winding **35**, an output or load winding **36**, an input winding **37**, with the windings **35**, **36** and **37** all being associated with core **31** but only the input winding **37** being associated with core **30**, as has been previously described.

Referring more specifically to FIG. **3**, the equivalent electrical schematic diagram of FIG. **4** illustrates a three-phase source applied across **40**, **41** and **42** of the three-phase connected input wiring **43**. The phenomenon that has been described in detail in connection with the single-phase mode of operation now exists in each leg **44**, **45** and **46** of the three-phase coil structure, the single-phase having provided a symmetry structure which is essential to a multiphase ferroresonant constant voltage transformer, which acts on the cores **30** and **31** as has already been described for a single-phase transformer. A three-phase output is generated in the terminals **46**, **47** and **48** of the three-phase output windings **40** having legs **51**, **52** and **53** connected to an output load **59**. Three-phase resonant circuit **54** has the three-phase resonant windings **55** having three legs **56**, **57** and **58** connected by means of conductors **60**, **61** and **62** to the resonant capacitance circuit **63** in three capacitance legs **64**, **65** and **66** with all the computations and winding schemes that apply to conventional multiphase or three-phase design, also applying to the present transformer as will be apparent to those of ordinary skill in the art.

Referring now to FIG. **5**, another embodiment is illustrated having toroidal cores and a three-phase winding arrangement, with three toroidal cores **70** and three toroidal cores **71** and a three-phase input winding **72** linked to cores **70** and **71** of each leg and with a three-phase output winding **73** connected to each core **71** along with the resonant winding **74** linking it to toroidal core **71**. This portion of the circuit illustrates the operation of a three-phase toroidal core winding without illustrating the complete resonance circuit as has been previously described.

It should also be noted at this point that while a thorough resonant constant voltage transformer has been provided, removal of the resonant circuit will produce a conventional transformer which is inherently current limiting and while applicant does not wish to be limited to any particular embodiment, the following values are provided by way of example of one operable model only, and applies to a three-phase transformer as illustrated by the schematic in FIG. **3**:

Functional description	Material	Quantity
Input winding	Magnet wire 34 AWG	1150 turns/coil
Resonant winding	Magnet wire 38 AWG	2800 turns/coil
Output winding	Magnet wire 26 AWG	196 turns/coil
Resonant capacitor	Sprague oiled filled luf, 660 VAC	3 units
Core No. **30**	EI 9/16 3ϕ 29 Gauge Grain Oriented Silicon Steel	5/8 inch thick
Core No. **31**	EI 9/16 3ϕ 29 Gauge Grain Oriented Silicon Steel	21/32 inch thick

Input connection	Delta three-phase
Output connection	Wye three-phase
Resonant connection	Wye three-phase
Load connection	Wye three-phase

Input volts RMS Line-Line

Terminal				
	40–41	155	185	215
	41–42			
	42–40			
Output volts RMS Line-Line Terminal				
	46–47	23.00	23.25	23.50
	47–48	23.00	23.25	23.50
	48–46	22.20	22.45	22.70
Calculated output unbalance		3.5%	3.5%	3.5%

A ferroresonant type of constant voltage transformer has been illustrated for use in single-phase and three-phase operation, but it should be clear that because of the symmetry of transformer any phase can be used as desired, without departing from the spirit and scope of the present invention. It is also anticipated that other embodiments and equivalents are within the scope of the invention including the use of inherent current limiting transformer features by the elimination of the resonant circuit.

Accordingly, the present invention is not to be construed as limited to the particular forms disclosed herein since these are to be regarded as illustrative rather than restrictive.

I claim:

1. A constant voltage transformer comprising in combination:

a. a plurality of input windings;

b. first magnetic core linked to each said input winding and adapted to absorb flux during an input voltage rise in said input windings;

c. second magnetic core linked to each said input winding;

d. a resonance circuit having a plurality of resonant windings coupled to at least one capacitance, each said resonant winding being linked to said second magnetic core and said resonance circuit being adapted to produce a resonance for producing secondary flux in said second magnetic core from capacitance current in said resonant circuit, said current being in time phase with the primary flux of the second core to produce an increase in the flux of said second core means whereby said second core will be saturated while said first core is still unsaturated; and a plurality of output windings linked to said second magnetic core for producing a substantially constant voltage output.

2. The transformer in accordance with claim 1 in which said input winding, said output winding and said resonance circuit are three-phase circuits whereby said transformer operates in a three-phase mode.

3. The apparatus according to claim 2 in which said first core means is single core having three input windings thereon, and said second core means is a single core having three input windings thereon, three resonant windings thereon, and three output windings thereon for three-phase operation.

4. A multiple-phase constant voltage ferroresonant transformer having a symmetry structure comprising in combination:

a. a plurality of input windings;

b. a first core linked to each said input winding;

c. a second core linked to each said input winding;

d. resonant circuit means having a plurality of resonant windings each coupled only with said second core; and

e. a plurality of output windings coupled only to said second core means for producing an output whereby the saturation fluxes on said second core occur at substantially the same time for a plurality phase constant voltage ferroresonant transformer.

5. The apparatus according to claim 4 having three input windings and three output windings for operation in a three-phase mode.

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