

Aug. 26, 1958

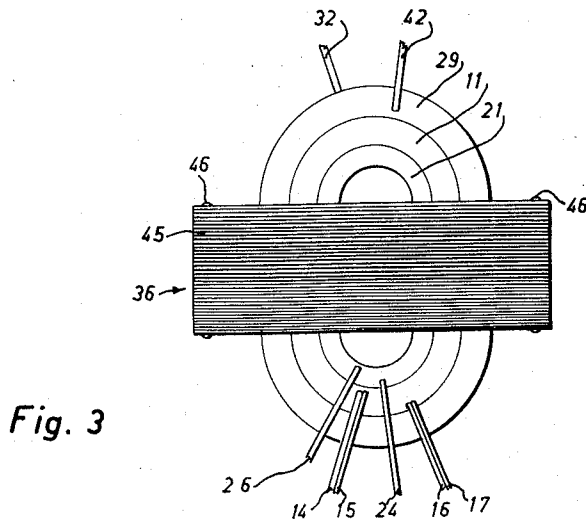
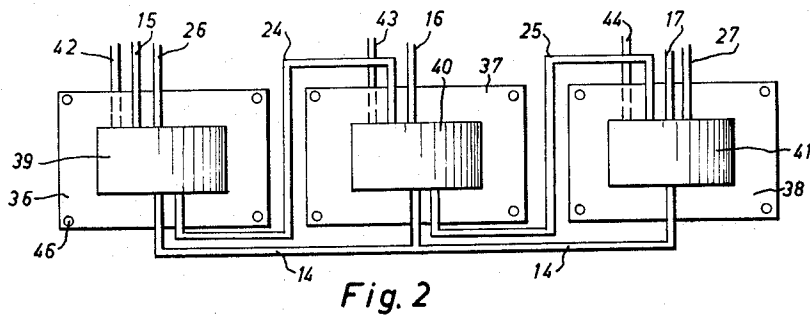
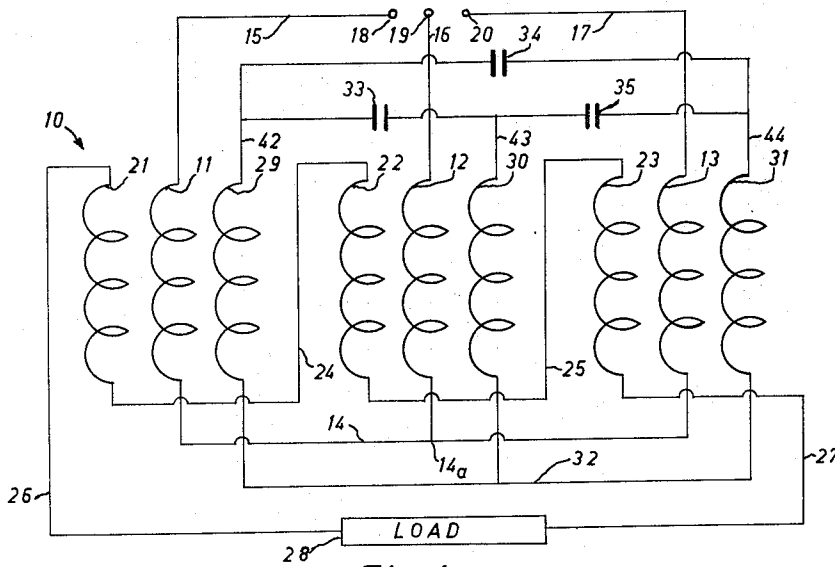
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2,849,674

FREQUENCY MULTIPLYING TRANSFORMER

Filed May 2, 1953

3 Sheets-Sheet 1



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FREQUENCY MULTIPLYING TRANSFORMER

Filed May 2, 1953

3 Sheets-Sheet 2

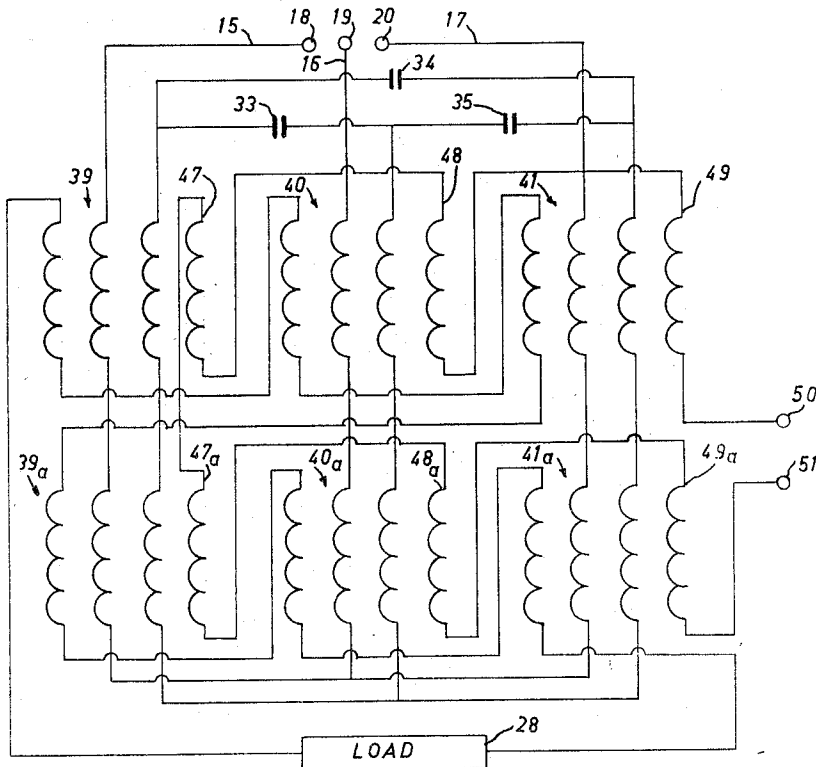


Fig. 4

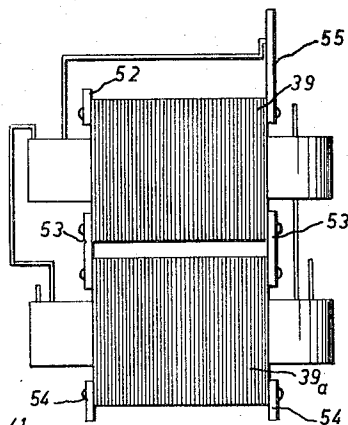


Fig. 5

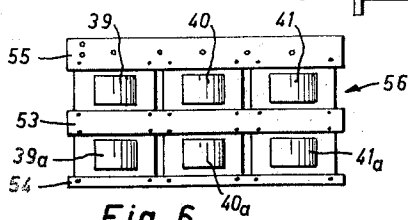


Fig. 6

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FREQUENCY MULTIPLYING TRANSFORMER

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3 Sheets-Sheet 3

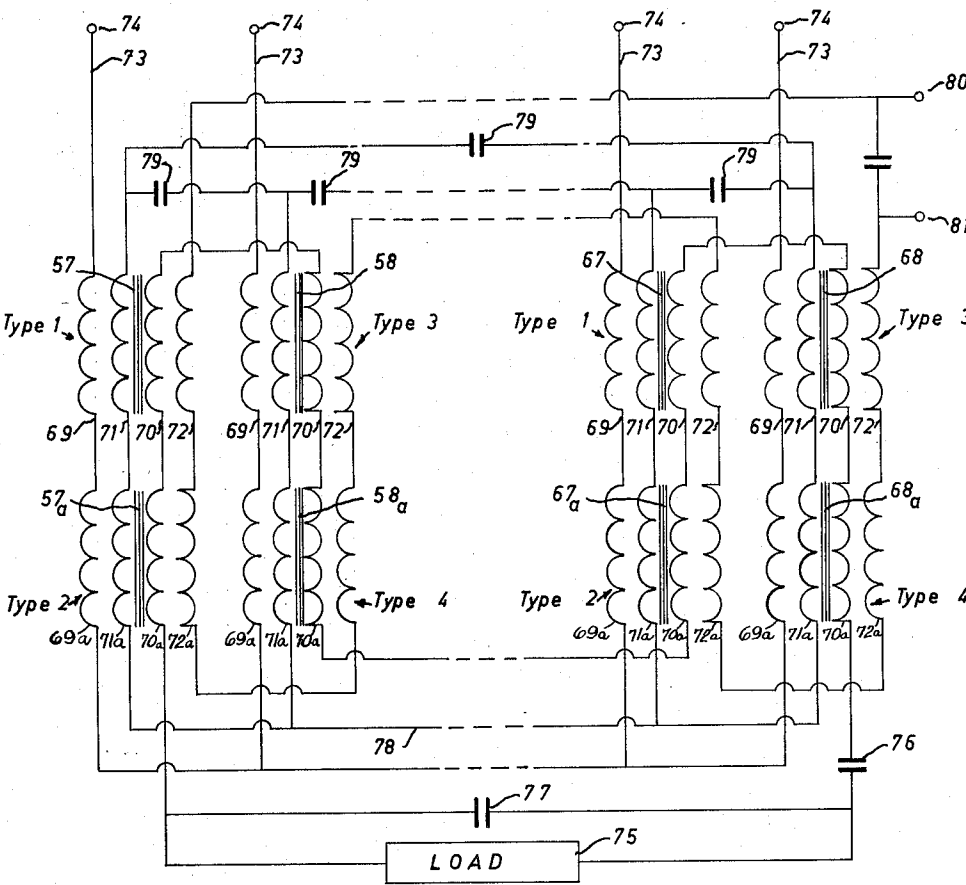


Fig. 7

1 57	3 58	1 59	3 60	1 61	3 62	1 63	3 64	1 65	3 66	1 67	3 68
2 57 _a	4 58 _a	2 59 _a	4 60 _a	2 61 _a	4 62 _a	2 63 _a	4 64 _a	2 65 _a	4 66 _a	2 67 _a	4 68 _a

Fig. 8

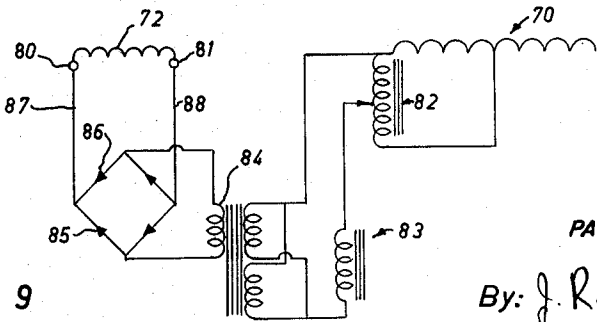


Fig. 9

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2,849,674

FREQUENCY MULTIPLYING TRANSFORMER

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Application May 2, 1955, Serial No. 505,426

7 Claims. (Cl. 321—68)

This invention relates to a frequency multiplying transformer having power factor correction.

This application is a continuation-in-part of my application Serial Number 317,347, filed October 28, 1952, assigned to the same assignee as the present application, now abandoned.

Devices for tripling the input frequency of multi-phase power source to single phase are known but are not adapted for use in power circuits for a number of reasons. The high frequency power output is relatively low for large size transformers. While prior devices are effective as a voltage sensitive amplifying device, the output voltage of the secondary windings varies widely with primary voltage variations and the reactance of the high frequency winding is very high. Moreover, at high operating flux densities of the core material at which the generation of high harmonics begins, the current in the primary windings is distorted to such an extent that power factor correction in the primary windings is not possible.

Prior frequency multiplying transformers do not demonstrate a power factor better than 0.5 regardless of the size of primary winding condensers. Accordingly, former devices of low power factor feed higher harmonics into the power lines and demonstrate a large physical size for small power output. Such prior devices are therefore not of general commercial practicability.

The invention has for its main object, the provision of a frequency multiplying transformer of satisfactory power factor correction for general commercial use.

Another object of the invention is to provide a frequency multiplying transformer embodying a compensating winding for each primary winding and magnetically coupled to the latter and a capacitance for each compensating winding adapted to compensate for current distortions in the primary windings.

It is a further object of the invention to provide a frequency multiplying transformer in which the power output can be controlled.

It is a still further object of the invention to provide a frequency multiplying transformer of a general form which may be adapted to multiplying the frequency of any multiphase source of power.

With these and other objects in view, the invention generally relates to a frequency multiplying transformer operative from a multi-phase source of electrical power of predetermined frequency and comprising in combination: a core providing a closed flux path for each phase of said source, a primary winding on each core connectable in phase to the source, a secondary winding for each primary winding, and a compensating winding magnetically coupled to each primary winding and connected in circuit with a capacitance to compensate for distortions in the power source.

The invention also concerns the provision of a control winding for each core adapted to control the saturation

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of the latter and thereby the power output of the secondary winding.

The disclosure herein setting forth separate cores providing a closed flux path for each phase of a power source should not be construed in any limiting sense as such cores may be partially combined physically and substantially the same operation results as set forth herein.

Other objects of the invention will be appreciated by a study of the following specification taken in conjunction with the accompanying drawings.

In the drawings:

Figure 1 is an electrical schematic of a simple form of frequency multiplying transformer of the invention;

Figure 2 shows a physical embodiment of the transformer of Figure 1;

Figure 3 is a plan view of one of the core structures of Figure 2;

Figure 4 is an electrical schematic of a further developed form of the invention illustrating control windings for control of power output;

Figure 5 is an end view of a physical form of the transformer of Figure 4;

Figure 6 is an elevation of the transformer of Figure 5;

Figure 7 is an electrical schematic of a frequency multiplying transformer of the invention as adapted to the multiplication of frequency of a twelve phase power source.

Figure 8 is a winding diagram for the windings of the transformer of Figure 7; and

Figure 9 is an electrical schematic of a preferred method of power output control operative from the power output of the transformer.

Referring to Figure 1, a frequency multiplying transformer 10 for a three phase source is shown and comprises primary windings 11, 12 and 13 commonly connected at one end by the leads 14 to a "floating" ungrounded juncture point 14a and connected at their other ends by leads 15, 16 and 17 to terminals 18, 19 and 20 adapted to be connected to a three phase source of electrical power of predetermined frequency. As in a conventional frequency multiplying system, the secondary windings 21, 22 and 23 are connected electrically in series by lines 24 and 25 and lines 26 and 27 to the load 28.

While attempts have been made to apply power factor correction directly to the primary windings in prior systems, the invention provides a magnetically coupled compensating winding for each primary as designated by numerals 29, 30 and 31 commonly joined at one end by the leads 32 and connected in delta arrangement with the capacitances 33, 34 and 35 at the other. The compensating windings are thus arranged so that the voltages thereacross are distorted by the harmonics and contain all the different harmonics and fundamentals except the third and multiples of it. Accordingly, the capacitances provided across the terminals of the compensating windings in appropriate phase connection will compensate for all distortions in line current and effect satisfactory power factor correction in the power supply line.

The simplified form of the frequency multiplying transformer of the invention shown schematically in Figure 1 is illustrated in its physical arrangement in Figure 2 where cores 36, 37 and 38 providing a complete or closed flux path for each phase of the power supply source carry windings 39, 40 and 41 embodying a primary, secondary and compensating winding in each case. Output is taken from the secondary windings by means of leads 26 and 27 and leads 15, 16 and 17 connect to the three phase source. Leads 42, 43 and 44 are connected to the

condensers 33, 34 and 35 (not shown). Connecting leads 14 join the lower ends of the primary windings as shown in Figure 1. Each set of windings is placed upon a closed E-shaped laminated core 45 held in assembly by bolts 46. As shown in Figure 3, the winding, for example, on the core 36, may comprise the output winding or secondary winding 21 in the innermost position; the input or primary winding 11 in an intermediate position and the compensating winding 29 in the outermost position. Each winding is preferably formed of relatively flat copper tubing suitably bound with insulation in a manner well known to skilled persons.

In many instances, it will be desired to provide a control over the power output of the transformer construction shown in Figures 1 to 3. For this purpose, a control winding may be provided on each core as indicated in Figure 4 wherein like numerals indicate like components. Thus the control windings 47, 48 and 49 are provided for each of the winding sets 39, 40 and 41 and are electrically connected in series to the terminals 50 and 51 through a further series of control windings 47a, 48a and 49a in reverse flux relation to the windings 39a, 40a and 41a to thereby provide a means of controlling core saturation of the various core parts (not shown) supporting the windings. More specifically, a control winding is provided on each effectively separate core. Each core is separated into two portions or parts so that two winding sets are provided for each phase as 39, 39a for one phase; 40, 40a for another phase; and 41, 41a for a third phase. Each winding set includes a part of a control winding adapted to saturate its core part in a sense opposite to that effected by the other part of the control winding to cancel out frequency effects in the control windings. As shown, the control windings are connected in series to terminals 50 and 51 and thus would function as a frequency multiplying winding were the cancelling effect of the reverse winding parts not provided.

In general, the control windings for each phase are distributed over two core parts adapted to be saturated oppositely by virtue of a reverse connection of one half-section of the control winding.

Accordingly, the direct current controlled transformer in its physical form as shown in Figure 5 embodies an upper core part 39 and a lower core part 39a for each phase supported by the longitudinal framing strips 52, 53 and 54 and the panel terminal strip 55 bolted to the core laminations and maintaining the cores in the stacked assembly 56 shown in Figure 6. The invention herein set forth is not limited in its application to the multiplication of three phase power but may be generally employed for the general multiplication of multi-phase electrical power in which the output frequency may be the fundamental phase multiple of the basic power source frequency.

In this connection, it is to be noted that it is not intended to limit the invention to an output of single phase power for once the form of the transformer of the invention as set forth herein is appreciated, skilled persons may modify the secondary windings for multi-phase output or may, for example, connect three single phase output transformers of the invention for three phase output of the secondaries with phase shift primary connections. Also, it is not intended that in referring to the number of phases of the power source that a limitation of conventional power line phase number is to be implied, for it may be of advantage to use a conventional phase multiplying device of well known construction to multiply a three phase power source to a greater phase number, for example, twelve phase.

In a simplified illustration of the invention as applied to a larger number of phases, a twelve phase source of power derived from a phase multiplying transformer delivering say twelve phase sixty cycle power, may be converted to single phase 720 cycle power by the form of the invention illustrated in Figure 7.

The twelve phase frequency multiplying transformer shown in Figure 7 is of the same general form as that of Figure 4 having a core providing a closed flux path for each phase, that is, the cores 57 to 68 (each comprising two core parts), each having a primary winding 69, 69a, a secondary or output winding 70, 70a, a compensating winding 71, 71a, and a control winding 72, 72a. To facilitate electrical connection and assembly of the various winding sets on their core parts 57 to 68a, certain of the windings may be reversed so that four types of windings are employed wherein type 1 on core part 57 has all the windings wound in the same direction; type 2 on core part 57a has the control winding wound in the reverse direction; type 3 winding on core part 58, has the secondary and control windings wound in the reverse direction and a type 4 winding on core part 58a has the secondary wound in the reverse direction. The relation of the winding types to the core parts is indicated in the winding diagram of Figure 8 wherein the upper figure in each block of the diagram indicates the type of winding for the core part identified by the core number in the block.

The leads 73 of the various primary windings are connected to the series of terminals 74 adapted to be connected to a twelve-phase source of power of predetermined frequency. The secondary windings 70, 70a are connected electrically in series across the load 75 through a condenser 76. It is also preferred to connect a condenser 77 in parallel with the load. Either one or both of the condensers 76 and 77 effect cancelling of the high reactance of the high frequency secondary and are preferably tuned in resonance at a frequency of 720 cycles in a twelve phase circuit having a sixty cycle power source. In this manner, the power output is limited only by the resistive components of the circuit. Note that as in the previous forms discussed, the compensating windings 71, 71a are connected commonly to the line 78 at one end and are connected in circuit relation with their various condensers 79 at the other ends thereof to provide compensation for all distortions in line current in the primary windings 69, 69a. As in the case of the form of transformer shown in Figure 4, the control windings 72 are connected for current flow in one direction in the upper set of core parts 57 to 68 and for current flow in the opposite direction relative to the lower sets of core parts 57a to 68a to cancel out unwanted alternating current components in the control windings. Accordingly, a D. C. voltage applied at terminals 80 and 81 will effect a core saturation power output control.

A useful method of obtaining direct current power for saturation control purposes is indicated in Figure 9 wherein the output or secondary windings 70, 70a have connected in parallel with a portion thereof, the variable transformer 82 connecting to a conventional stepdown transformer and voltage regulator device 83, the output winding 84 of which connects to the full wave rectifying circuit 85 having conventional dry plate rectifying devices 86 therein and delivering a full wave rectified output by lines 87 and 88 to the terminals 80 and 81 of control windings 72, 72a. By manual variation of the variable transformer 82, the direct current power applied to the control windings 72 may be varied to provide a close control over the saturation of the various core parts and the output of the transformer shown in Figure 7. The same control arrangement can be employed for the transformer form illustrated in Figure 4. The control has been shown to be effective as for example in controlling an induction heating transformer made according to the invention. A full wave feedback class of control as illustrated in Figure 9 enabled a fifty kilowatt one hundred and eighty cycle output of a frequency multiplying transformer of the invention to be controlled between twenty-five percent and one hundred percent of full power accompanied by a voltage control between fifty percent and one hundred percent.

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It will be apparent that a wide range of output frequency and phase number is available for the design of a frequency multiplying transformer of the invention having regard to conventional phase multiplication of line power and the art of multi-phase winding connections as applied to the teachings herein.

What I claim as my invention is:

1. A frequency multiplying transformer connectable to a multi-phase source of electrical power of predetermined frequency and adapted to convert said power to power of greater frequency with power factor correction and comprising in combination: a core providing a closed flux path for each phase of said source; a primary winding on each closed flux path of said core and connectable to said source; a secondary winding on each closed flux path of said core; means connecting said secondary windings electrically in series for each power phase obtainable from said secondary windings; a compensating winding magnetically coupled to each primary winding; a capacitance for said compensating windings; means electrically connecting said compensating windings and capacitances therefor to compensate for current distortions in said primary windings; a control winding on each closed flux path of said core for controlling saturation thereof; and means for applying direct current to said control windings for controlling the power output of said secondary windings.

2. A frequency multiplying transformer connectable to a multi-phase source of electrical power of predetermined frequency and adapted to convert said power to power of greater frequency with power factor correction and comprising in combination: a core providing a closed flux path for each phase of said source; a primary winding on each closed flux path of said core and connectable to said source; a secondary winding on each closed flux path of said core; means connecting said secondary windings electrically in series for each power phase obtainable from said secondary windings; a compensating winding magnetically coupled to each primary winding; a capacitance for said compensating windings; means electrically connecting said compensating windings and capacitances therefor to compensate for current distortions in said primary windings; a control winding on each closed flux path of said core for controlling saturation thereof; means for applying direct current to said control windings; and means for adjusting the direct current power applied to said control windings to control the power output of said secondary windings.

3. A frequency multiplying transformer connectable to a multi-phase source of electrical power of predetermined frequency and adapted to convert said power to power of greater frequency with power factor correction and comprising in combination: a core providing a closed flux path for each phase of said source; a primary winding on each closed flux path of said core and connectable to said source; a secondary winding on each closed flux path of said core; means connecting said secondary windings electrically in series for each power phase obtainable from said secondary windings; a compensating winding magnetically coupled to each primary winding; a capacitance for said compensating windings; means electrically connecting said compensating windings and capacitances therefor to compensate for current distortions in said primary windings; a control winding on each closed flux path of said core for controlling saturation thereof; means for applying direct current to said control windings for controlling the power output of said secondary windings; a variable transformer energizable by said secondary windings; voltage rectifying means including a regulating device connected to said variable transformer and providing therefrom a controllable direct current source of power; and means electrically connecting said direct current source of power to said control windings.

4. A frequency multiplying transformer connectable to a multi-phase source of electrical power of predetermined

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frequency and adapted to convert said power to power of greater frequency with power factor correction and comprising in combination: a core providing a closed flux path for each phase of said source; a primary winding on each closed flux path of said core and connectable to said source; a secondary winding on each closed flux path of said core; means connecting said secondary windings electrically in series for each power phase obtainable from said secondary windings; a compensating winding magnetically coupled to each primary winding; a capacitance for said compensating windings; means electrically connecting said compensating windings and capacitances therefor to compensate for current distortions in said primary windings; a control winding on each closed flux path of said core for controlling saturation thereof; means for applying direct current to said control windings for controlling the power output of said secondary windings; a variable transformer energizable by said secondary windings; full wave voltage rectifying means including a regulating device connected to said variable transformer and providing therefrom an adjustable direct current source of power; and means electrically connecting said direct current source of power to said control windings.

5. A frequency multiplying transformer connectable to a multi-phase source of electrical power of predetermined frequency and adapted to convert said power to power of greater frequency with power factor correction and comprising in combination: a separate core providing a closed flux path for each phase of said source; a primary winding on each closed flux path of said core and connectable to said source; a secondary winding on each closed flux path of said core; means connecting said secondary windings electrically in series for each power phase obtainable from said secondary windings; a compensating winding coupled to each primary winding; a capacitance for said compensating windings; means electrically connecting said compensating windings and capacitances therefor to compensate for current distortions in said primary windings; a control winding on each closed flux path of said core for controlling saturation thereof; means for applying direct current to said control winding for controlling the power output of said secondary windings; means for connecting said secondary windings to a load; and capacitance means for cancelling the high reactance of said secondary windings.

6. A frequency multiplying transformer connectable to a multi-phase source of electrical power of predetermined frequency and adapted to convert said power to power of greater frequency with power factor correction and comprising in combination: a core providing a closed flux path for each phase of said source; a primary winding on each closed flux path of said core and connectable to said source; a secondary winding on each closed flux path of said core; means connecting said secondary windings electrically in series for each power phase obtainable from said secondary windings; a compensating winding magnetically coupled to said primary windings; a capacitance for each compensating winding; means electrically connecting said compensating windings and capacitances therefor to compensate for current distortions in said primary windings; a control winding on each closed flux path of said core for controlling saturation thereof; means for applying direct current to said control windings to provide control over the power output of said secondary windings; said saturable core portions each being in the form of an individual core having a portion of each of said windings thereon; and structural means supporting said individual cores in stacked array.

7. A frequency multiplying transformer connectable to a multi-phase source of electrical power of predetermined frequency and adapted to convert said power to power of greater frequency and comprising in combination: a core providing a closed flux path for each phase of said source; a primary winding on each closed flux path of said core and connectable to said source; a secondary winding on each closed flux path of said core; means connecting said

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secondary windings electrically in series providing a single power phase obtainable from said secondary windings; a control winding on each closed flux path of said core for controlling saturation thereof; means for applying direct current to said control windings for controlling the power output of said secondary windings; a variable transformer energizable by said secondary windings; voltage rectifying means including a regulating device connected to said variable transformer and providing therefrom a controllable direct current source of power; and means electrically connecting said direct current source of power to said control windings.

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