

Aug. 4, 1964

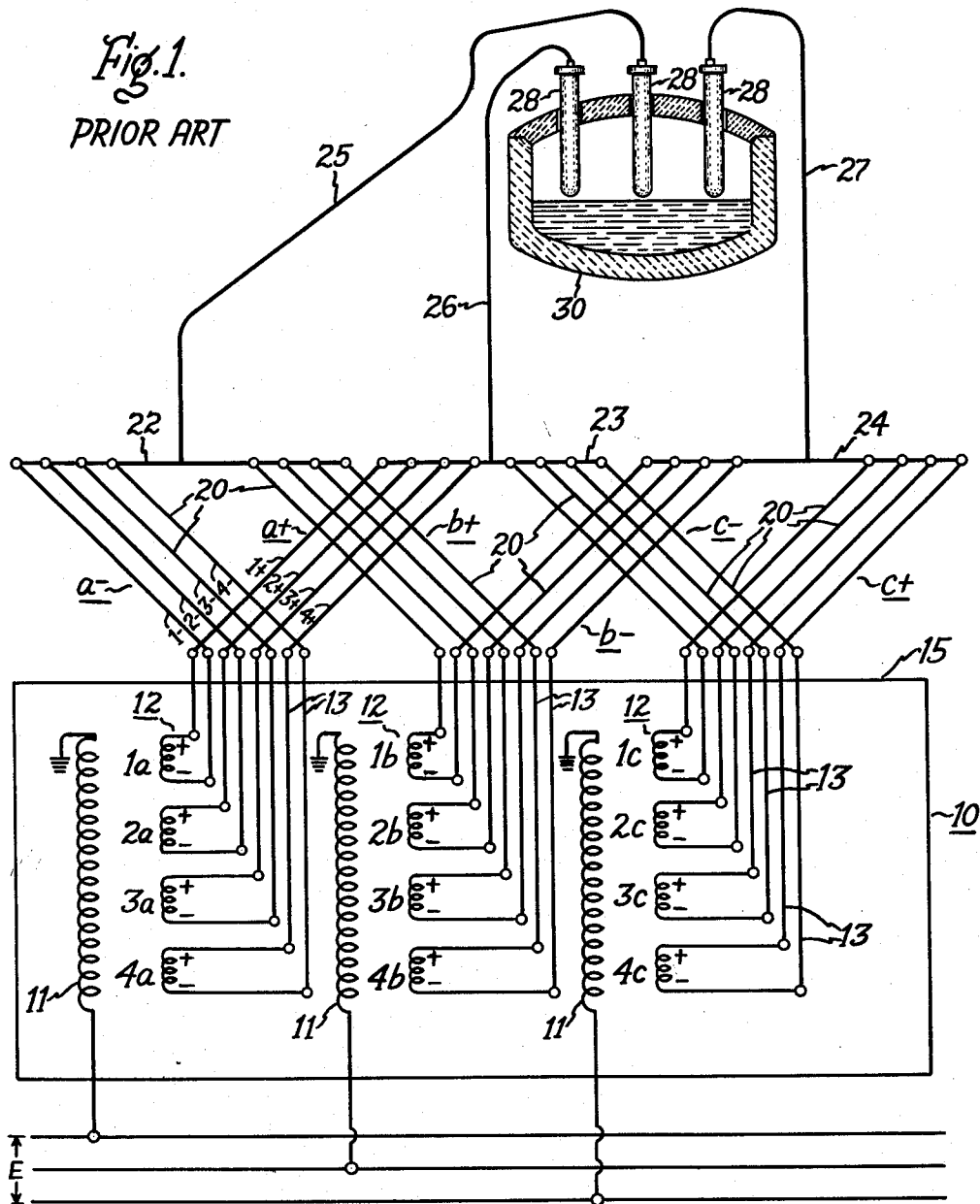
J. C. RUSS

3,143,699

ELECTRICAL REACTANCE BALANCING APPARATUS

Filed Aug. 25, 1961

5 Sheets-Sheet 1



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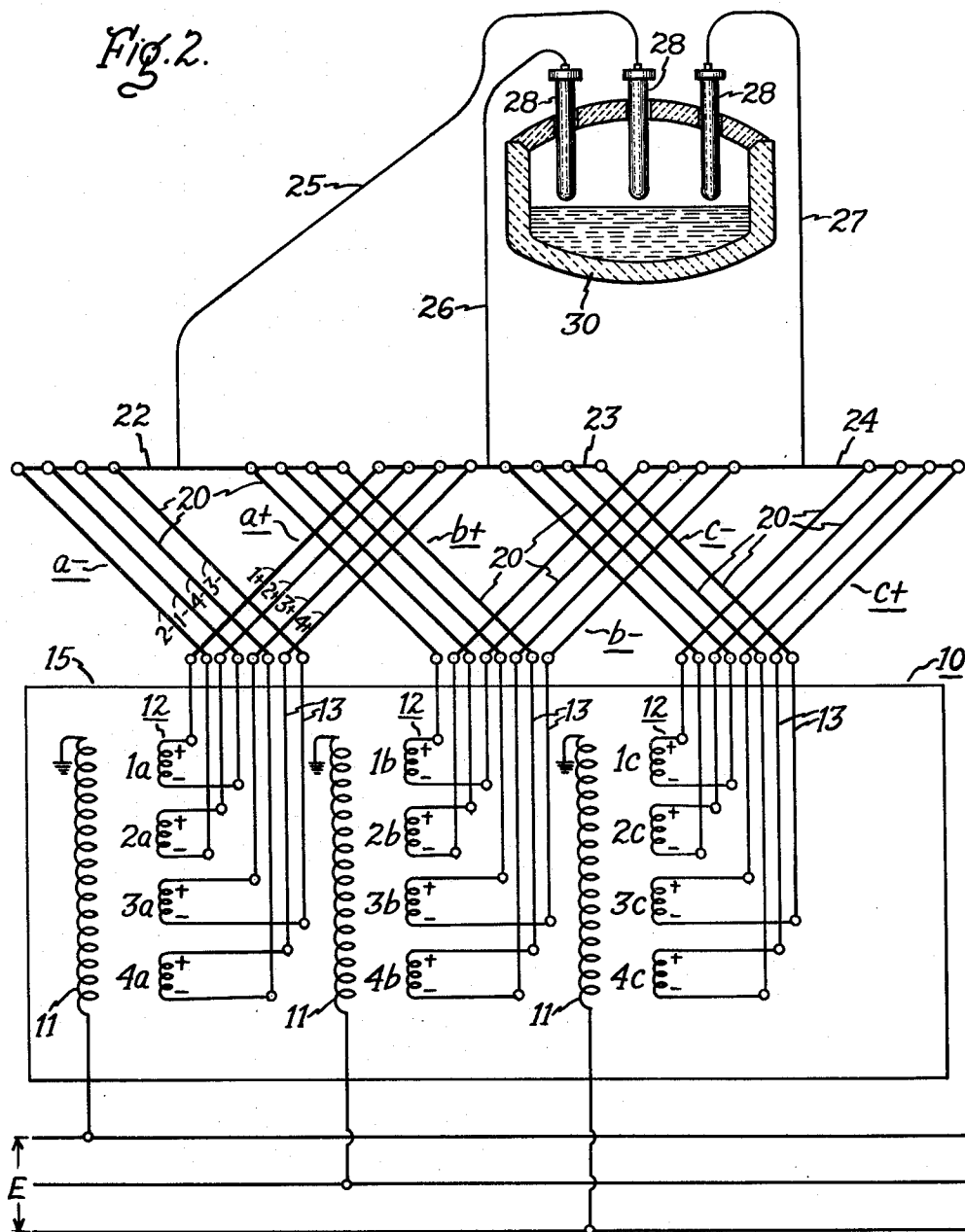
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ELECTRICAL REACTANCE BALANCING APPARATUS

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5 Sheets-Sheet 2



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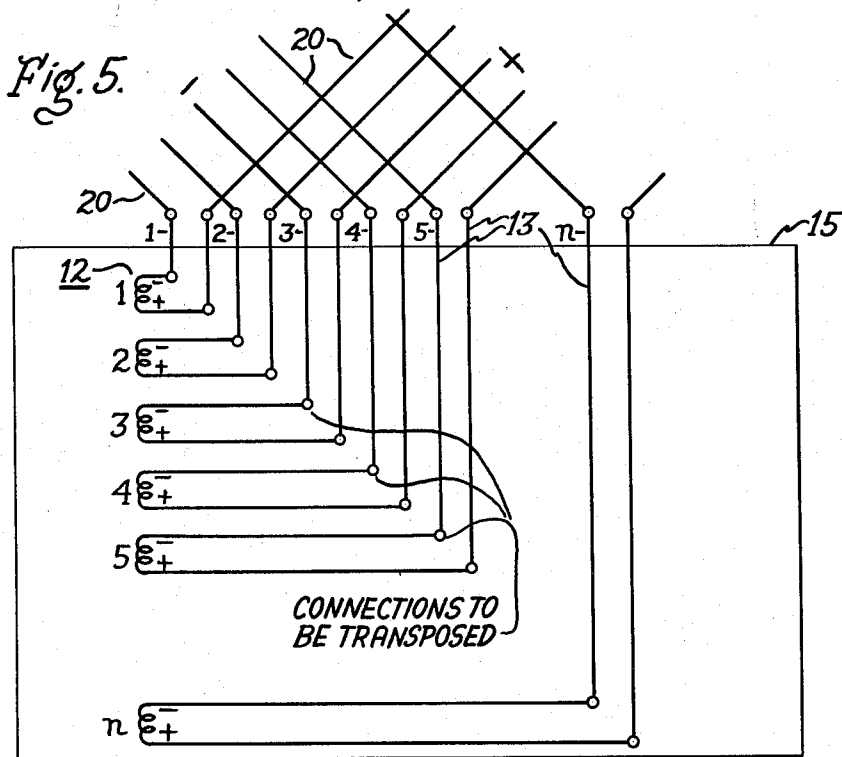
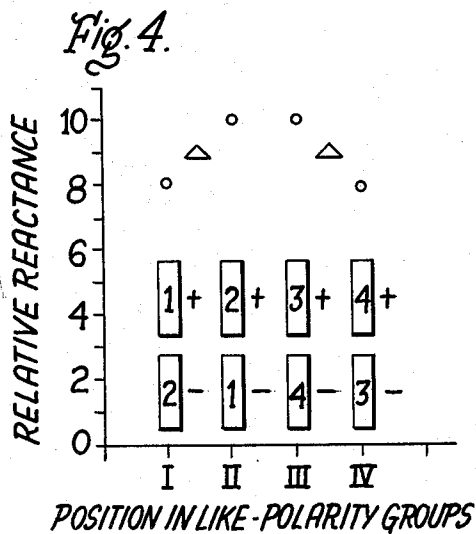
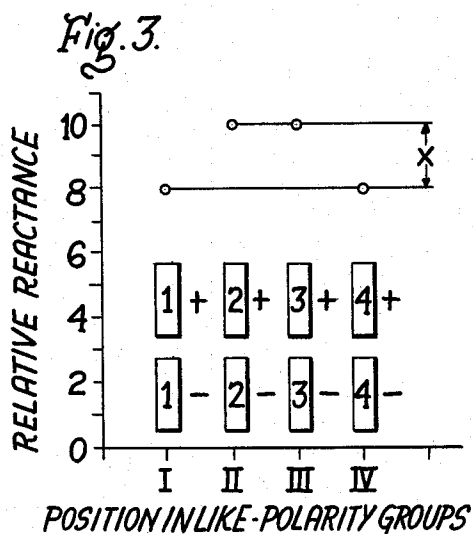
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ELECTRICAL REACTANCE BALANCING APPARATUS

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5 Sheets-Sheet 3



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ELECTRICAL REACTANCE BALANCING APPARATUS

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5 Sheets-Sheet 4

Fig. 6.
PRIOR ART

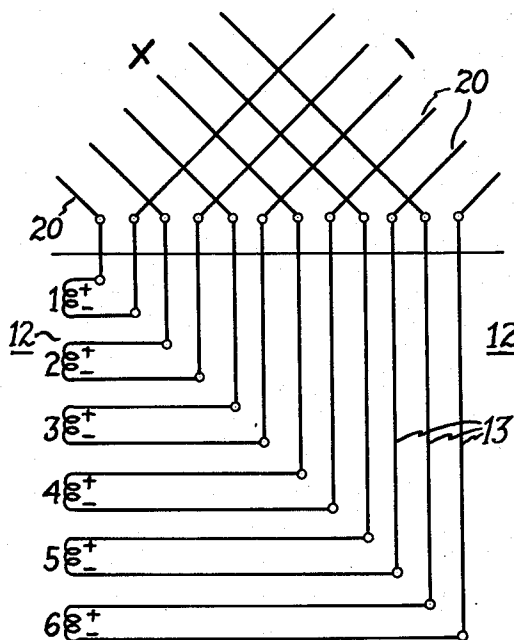
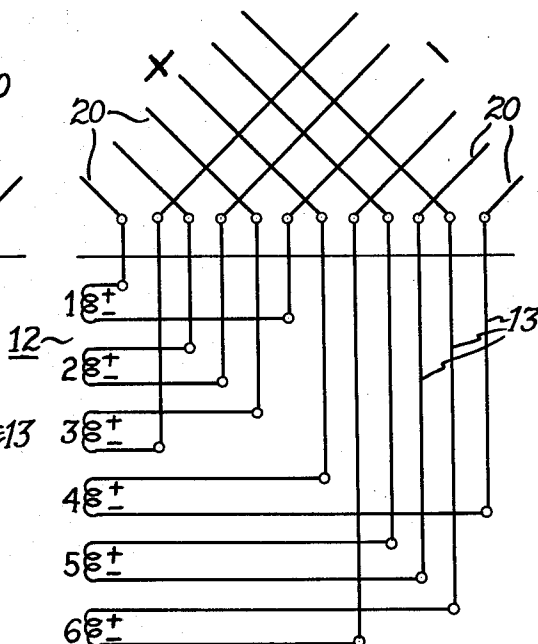


Fig. 7.



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3,143,699

ELECTRICAL REACTANCE BALANCING APPARATUS

Filed Aug. 25, 1961

5 Sheets-Sheet 5

Fig. 8.

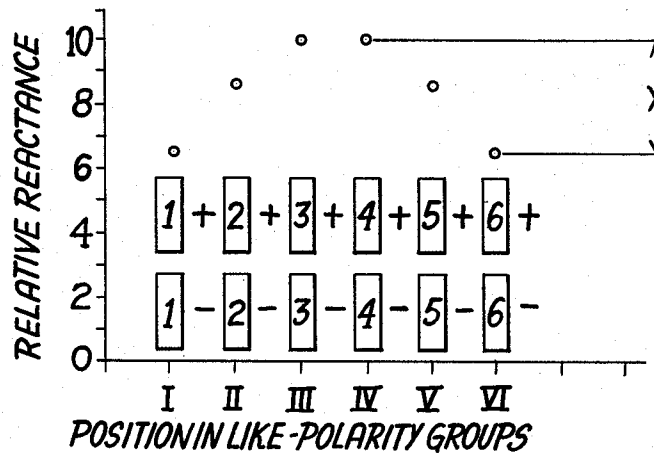
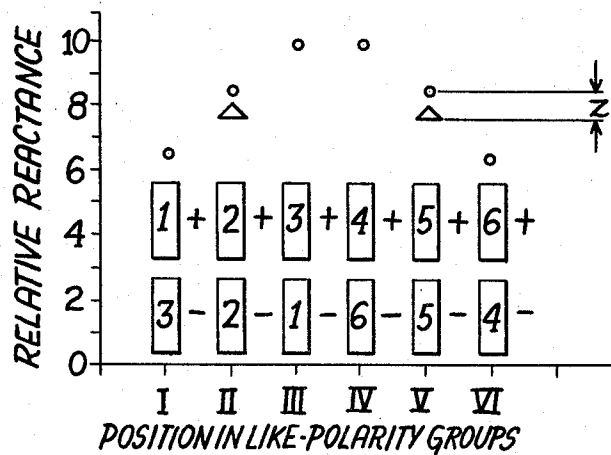


Fig. 9.



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1

3,143,699

**ELECTRICAL REACTANCE BALANCING
APPARATUS**

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Filed Aug. 25, 1961, Ser. No. 133,935
9 Claims. (Cl. 323—48)

This invention relates to electrical apparatus having a plurality of windings, and more in particular to improved connection arrangements that reduce imbalances in the relative reactance and current of circuits including said windings.

Stationary electrical induction apparatus, such as transformers and the like are often arranged to produce currents of exceedingly large magnitude. One example of such apparatus is the so-called "furnace" transformer of the type adapted to be connected to electric arc furnaces. The high voltage windings of such transformers are usually connected to an input power supply of three-phase alternating current, and the winding ratios are often arranged so that the transformers supply the furnaces with electrode currents in excess of 10,000 amperes at relatively low voltages. The low voltage winding for each phase of a furnace transformer is usually divided into a plurality of parallel-connected winding sections, which are arranged so that their corresponding ends have the same polarity.

Where the output currents of a furnace transformer are large enough to require parallel connected winding sections, thick leads are connected to each winding section to carry the currents to the outside of the transformer tank. As is well known in the prior art, leads of opposite polarity should be arranged adjacent each other, so that reactance imbalance caused by differences in leakage flux within the transformer tank are reduced. However, after the leads emerge from the transformer tank, it is advantageous for well known reasons to segregate into groups of like-polarity, the external conductors employed to make a delta connection between the phase of the transformer for the purpose of conducting current to the electrodes in an electric arc furnace. The relative position of the external conductors in the like-polarity groups with respect to each other causes the leakage flux linking the conductors to be different. The external conductors in the center of a like-polarity group have a higher reactance than those at the outside of the group. This results in current and reactance imbalances between the parallel-connected circuits that include the low voltage winding sections, the internal leads, and the external conductors.

The current and reactance imbalances are undesirable because the output of the transformer is usually taken as proportional to the current measured by a current transformer associated with one of the internal leads for one of the low voltage winding sections; to the extent that current imbalances occur between winding sections, the output measurement will be incorrect. Furthermore, current imbalances can result in overheating of one winding section while another winding section is not producing current up to its design capacity. My invention is based on the discovery that current and reactance imbalances between the parallel-connected circuits, caused by current and reactance imbalances that occur between the external conductors in the like-polarity groups on the outside of the transformer tank, are affected by the sequence in which the winding sections are connected to the leads on the inside of the transformer.

Accordingly, it is an object of my invention to provide electrical apparatus in which current and reactance imbalances caused by prior art winding arrangements are reduced.

Another object is to provide improved arrangements for

2

making internal connections to the winding sections of a transformer that results in a reduction of current and reactance imbalances between circuits including the winding sections.

Another object is to provide winding arrangements for furnace transformers that reduce current and reactance imbalances.

A further object is to provide furnace transformers with winding interconnection arrangements that reduce reactance differences between circuits including conductors segregated into groups of like-polarity on the outside of the transformer enclosure.

A further object is to provide arrangements for connecting winding sections of a transformer to external conductors that reduce current and reactance imbalances to theoretically minimum values for certain typical winding arrangements.

Other objects and advantages of the invention will become apparent from the drawings, specification, and claims, and the scope of the invention will be pointed out in the claims.

Briefly stated, according to one aspect of my invention, a transformer may have a winding divided into more than two winding sections connected in parallel. The positive end of each winding section is connected to an internal lead and the negative end of each winding section is connected to another internal lead. The positive and negative leads from each winding section may be positioned at the same end of the transformer. The leads are connected to other conductors externally of the transformer enclosure. The winding produces an output current in the external conductors sufficiently large to cause reactance and current imbalance between the external conductors that varies according to the position of the conductors with respect to each other; the imbalances are magnified when the external conductors are segregated into groups of like-polarity. My invention resides in a connection arrangement between winding sections and the internal leads in which at least one winding section that has a high reactance external conductor connected to one of its ends has low reactance external conductors connected to its other ends.

Formulas have been derived for determining which winding sections and leads should be interconnected to produce optimum results; however, it is to be understood that the invention is not limited to arrangements in which the exact transpositions specified by the formulas are employed, in that reactance imbalances may be reduced, though not necessarily minimized, by arrangements other than the calculated interconnections.

In the drawing.

FIG. 1 is a schematic circuit diagram showing the connections between a furnace transformer and an electric arc furnace according to the prior art.

FIG. 2 is a schematic circuit diagram corresponding to FIG. 1 except that the inter-connections between transformer winding sections and outgoing leads are arranged in accord with the teachings of my invention.

FIG. 3 is a theoretical graph of relative reactance versus external conductor position for a typical furnace transformer arrangement having four winding sections connected in the prior art circuit of FIG. 1.

FIG. 4 is a theoretical graph of relative reactance versus external conductor position corresponding to FIG. 3, except that the windings are connected in accord with my teachings, as shown in FIG. 2.

FIG. 5 is a schematic circuit diagram of one phase of a prior art winding arrangement having n sections.

FIG. 6 is a simplified, schematic circuit diagram of one phase of a furnace transformer winding arrangement having six winding sections connected to internal leads in accord with prior art practices.

3

FIG. 7 is a simplified, schematic circuit diagram of a six-section furnace transformer winding corresponding to FIG. 6, except that the windings are connected to the internal leads in accord with the teachings of my invention.

FIG. 8 is a theoretical graph of relative reactance versus external conductor position for a typical furnace transformer arrangement having six winding sections connected in the prior art circuit shown in FIG. 6.

FIG. 9 is a theoretical graph of relative reactance versus external conductor position corresponding to FIG. 8, except that the windings are connected in accord with my teachings, as shown in FIG. 7.

Turning now to the drawings, FIG. 1 shows a typical prior art three-phase furnace transformer arrangement. The transformer 10 has its high voltage windings 11 connected to a suitable input source E of three phase A.C. power. The low voltage winding 12 for each phase may be divided into four parallel-connected winding sections 1, 2, 3, and 4; the letters *a*, *b*, and *c* associated with the winding sections designate the respective phases of the transformer. Each end of each winding section is connected to an internal lead 13; the leads 13 are disposed adjacent each other at one end of the transformer and pass through a sealed enclosure tank 15, containing the transformer, as schematically indicated in FIG. 1. Those skilled in the art will be aware that each winding section in each phase may be subdivided into a plurality of parallel subsections, with all subsections of each winding section being connected in like manner to the same leads 13.

After the leads 13 emerge from the transformer enclosure 15, they are connected to external conductors 20, which are employed to achieve a three-phase delta connection. It is advantageous for well known reasons to segregate the conductors 20 in each phase into groups of like-polarity. The like-polarity groups are designated by the notations *a*+, *a*−, *b*+, *b*− and *c*+, *c*−, to indicate the phase and relative polarity of the respective groups. Those skilled in the art will realize that the polarities referred to are instantaneous and change with the frequency of the power supply, which is ordinarily 60 cycles per second.

The delta connection may be closed by connecting the group *a*− and the group *b*− to a common conductor 22, connecting the group *a*− and the group *c*− to a common conductor 23, and connecting the group *b*− and the group *c*− to a common conductor 24. The conductors 22, 23, and 24, respectively are then connected by conductors 25, 26, and 27 to the electrodes 28 of an electric arc furnace 30. The internal leads 13, external conductors 20, and the conductors 22–27 must be capable of carrying large currents to the electrodes 28. Consequently, these circuit elements are usually made from one or more thick, rigid copper or aluminum bars; however, to simplify the drawing, they have all been illustrated as single conductors.

In the prior art arrangement of FIG. 1, the internal connection arrangement between the ends of the winding sections 1–4 and the internal leads 13 is sequential, with the leads 13 connected to opposite ends of the same winding section being adjacent each other. This results in the external conductors 20 connected to each winding section both occupying the same relative position in the like-polarity groups. For example, as illustrated for phase *a* in FIG. 1, the + and − conductors 20 connected to the winding sections 1*a* and 4*a* occupy the outside positions in their like-polarity groups, and the + and − conductors 20 connected to the winding sections 2*a* and 3*a* occupy the interior positions in their like-polarity groups. This same relationship occurs in the phase *b* and *c*; however, to shorten the description of the invention, only the phase *a* has been described with reference to all figures in the drawing.

As is well known in the art, when the transformer 10 produces large output currents, a reactance balance among

4

the leads 13 on the inside of the transformer may be obtained by disposing leads of opposite polarity adjacent each other in the manner indicated. However, when the leads 13 are connected to the external conductors 20, which are segregated into groups of like-polarity, large current and reactance imbalances between different conductors result from this type of arrangement. The conductors 20 at the interior positions in the like-polarity groups have relatively high reactance, which diminishes the amount of current they carry. The reason is that the conductors at the interior positions are linked by flux from the conductors at the outer positions as well as by the flux that they produce themselves. Thus, for example, both conductors 20 connected to the winding section 2*a* will be in relatively high reactance positions when compared with both conductors 20 connected to the winding section 1*a*.

My invention is directed to predetermined arrangements for internally connecting various sections of the low voltage windings 12 to the leads 13 to achieve a reduction in current and reactance imbalances in the circuits of the parallel-connected winding sections that occur because of the imbalance in the like-polarity groups of conductors 20 on the outside of the transformer. Interconnection arrangements in accord with my teachings result in at least one winding section having an external conductor in a high reactance position connected to one of its ends being connected at its other end to a different external conductor having a low reactance position. In most situations reactance imbalances are minimized by connecting each of two winding sections at one end to an external conductor occupying a minimum reactance position and connecting the other end of each winding section to an external conductor occupying a maximum reactance position.

Turning now to FIG. 2, the circuit arrangement is the same as that of FIG. 1, except that the internal connections between the winding sections 12 and the leads 13 are in accord with my teachings. When compared with the prior art connections in FIG. 1, FIG. 2 reveals the connections between the winding sections 1 through 4 of each phase and their associated leads 13 to be transposed so that each winding section is connected at one end to an external conductor 20 having a high reactance position in its like-polarity group, and connected at its other end to an external conductor 20 having a low reactance position. This was accomplished by transposing the minus polarity connections for the winding section 1 in each phase with the minus polarity connections for the sections 2 in each phase, and by transposing the minus polarity connection for the section 3 in each phase with the minus polarity connection for the section 4 in each phase. For example, the conductors 20 in the group *a*− are connected to the winding sections in the sequence 1, 2, 3, 4, but the corresponding conductors 20 in the group *a*− are connected to the winding sections in the sequence 2, 1, 4, 3. Thus, each winding section is connected to one conductor 20 having a low reactance outside position and to one conductor 20 having a high reactance interior position.

The reduction of imbalances between winding sections can be better understood by reference to FIGS. 3 and 4, which show graphs based on theoretical calculations of relative reactance for typical prior art furnace transformer arrangements in which the conductors 20 are the same length. The relative reactance of the conductors 20 in the like-polarity groups is plotted against the position of the conductors 20 in their respective groups, and the value of the reactance for each position is designated by a dot. The positions numbered I–IV represent the location of the conductors 20 adjacent each other from left to right. The positions I and IV are the low reactance outside positions, and the positions II and III are the high reactance interior positions. The small rectangles are intended to represent end views of the conductors 20 occupying the respective positions, and the polarity and

5

winding section to which each conductor is connected are designated by appropriate sign and number.

FIG. 3 represents the prior art arrangement shown in FIG. 1 wherein both conductors 20 connected to the winding sections 1 and 4 occupy the low reactance outside positions, and both conductors connected to the winding sections 2 and 3 occupy the high reactance interior positions. The outside positions I and IV have a theoretical relative reactance of 8 and the interior position II and III have a theoretical relative reactance of 10. Thus the maximum reactance imbalance x between the conductors 20 for any two winding sections is 2.

FIG. 4 represents my transposed arrangement of FIG. 2. The designations for the conductors in each position show that each winding section is connected to one conductor occupying a high reactance interior position and to one conductor occupying a low reactance outside position. The result is that each winding section is connected to one conductor having a reactance of 10 and connected to another conductor having a reactance of 8. The average relative reactance for the conductors 20 for all winding sections is thus 9, as indicated by the triangles in FIG. 1. Thus, the reactance imbalance between winding sections due to the imbalance of conductors 20 has been reduced to zero by the practice of my invention.

Formulas have been derived for determining the internal connection arrangement between winding sections and leads that minimizes reactance imbalances for windings having any given number of parallel-connected sections. The formulas can be explained with reference to FIG. 5, which is a simplified circuit diagram for one phase of a transformer having a low voltage winding 12 with n circuits connected to leads 13 which pass through an enclosure 15, and are then connected to external conductors 20 which are segregated into groups of like-polarity on the outside of the transformer. The winding sections will be arranged in a predetermined first sequence, with the section at one end of the sequence being assigned the number 1, and the remaining sections numbered consecutively. In the example illustrated in FIG. 5, the winding sections are arranged one above the other with the uppermost section being assigned the number 1. The internal leads 13 will be arranged in a predetermined second sequence, with the lead of the polarity to be transposed at one end of the sequence being assigned the number 1, and the remaining leads of the same polarity numbered consecutively. In the example illustrated in FIG. 5, the leads are arranged side by side with the leftmost negative lead being assigned the number 1.

To minimize reactance imbalances of n parallel-connected circuits occurring in the portion of the circuits where the conductors 20 are segregated into groups of like-polarity, one connection (i.e. either negative or positive) between the winding sections and the internal conductors 13 should be transposed in the following manner:

Case I.—When “ n ” is an even number greater than 2:

Transpose one connection in circuit number

$$\left(\frac{n+2}{2}-a\right)$$

with the corresponding connection in circuit number (a), and

Transpose one connection circuit

$$\left(\frac{n}{2}+a\right)$$

with the corresponding connection in circuit number ($n+1-a$).

When

$$\frac{n}{2}$$

is an even number, evaluate the above for

$$a=1, 2, 3, \text{ etc. up to } \frac{n}{4}$$

6

When

$$\frac{n}{2}$$

is an odd number, evaluate the above for

$$a=1, 2, 3, \text{ etc. up to } \frac{n+2}{4}$$

Case II.—When “ n ” is an odd number greater than 1:

10 Transpose one connection in circuit number

$$\left(\frac{n+3}{2}-a\right)$$

with the corresponding connection in circuit number (a) and

transpose one connection in circuit number

$$\left(\frac{n+1}{2}+a\right)$$

20 with the corresponding connection in circuit number ($n+1-a$);

or

transpose one connection in circuit number

$$\left(\frac{n+1}{2}-a\right)$$

with the corresponding connection in circuit number (a), and

transpose one connection in circuit number

$$\left(\frac{n-1}{2}+a\right)$$

with the corresponding connection in circuit number ($n+1-a$).

35 When

$$\left(\frac{n+1}{4}\right)$$

is a whole number, evaluate for the above for

$$a=1, 2, 3, \text{ etc. up to } \frac{n+1}{4}$$

When

$$\left(\frac{n+1}{4}\right)$$

is not a whole number, evaluate the above for

$$a=1, 2, 3, \text{ etc. up to } \frac{n+3}{4}$$

By employing all of the transpositions calculated with the above formulas, reactance and current imbalances can be reduced to a theoretical minimum in typical furnace transformer arrangements where the conductors 20 in the like-polarity groups are all the same length.

55 An example of how the above formulas are employed is given below with reference to FIG. 6, which shows the prior art connection arrangement for one phase of a furnace transformer low voltage winding 12 divided into six parallel-connected sections. The transpositions that should be made for a six section winding according to the above formulas can be calculated as follows:

Since the winding is divided into 6 sections, “ n ” is an even number, and the formulas applicable to Case I should be employed.

65 Since

$$\frac{n}{2}$$

is an odd number, the values for “ a ” are determined by

70 solution of

$$\left(\frac{n+2}{4}\right)$$

which equals 2. This indicates that “ a ” is to be evaluated for the values 1 and 2.

75

7

Evaluation of the formulas for Case I for the values of $a=1$ and $a=2$ result in the following transpositions:

For $a=1$:

$$\left(\frac{n+2}{2}-a\right)=3$$

which is to be transposed with 1,

and

$$\left(\frac{n}{2}+a\right)=4$$

which is to be transposed with $(n+1-a)$, which=6.

For $a=2$:

$$\left(\frac{n+2}{2}-a\right)=2$$

which is to be transposed with 2 (this calculation indicates that the connections between the winding sections 2 and the leads 13 are to remain unchanged);

and

$$\left(\frac{n}{2}+a\right)=5$$

which is to be transposed with $(n+1-a)=5$. (This calculation also indicates that the connections between the winding sections 5 and the leads 13 are to remain unchanged.)

The above calculations reveal that either lead from the winding section 1 is to be transposed with the corresponding polarity lead from the winding section 3, and the corresponding polarity lead from section 4 is to be transposed with the corresponding polarity lead from section 6, and the leads from the winding sections 2 and 5 are to remain the same. This improved arrangement has been illustrated in FIG. 7, which is identical to FIG. 6, except that the above transpositions have been made.

The graphs in FIGS. 8 and 9 correspond to those in FIGS. 3 and 4 in that they show the reduction of reactance imbalance over the prior art obtained by the practice of my invention for a six section furnace transformer winding. The dots indicate the relative reactance of the conductors 20 in like-polarity groups occupying the respective positions designated I-VI from left to right, and in all other respects the notations FIGS. 8 and 9 indicate the same things as the corresponding notations in FIGS. 3 and 4.

FIG. 8 represents the prior art arrangement shown in FIG. 6, wherein the conductors 20 connected to the winding sections 1 and 6 occupy the lowest reactance positions, the conductors connected to the winding sections 3 and 4 occupy the highest reactance positions and the conductors connected to the winding sections 2 and 5 occupy intermediate reactance positions. The maximum imbalance y occurs between the outside winding sections (1 and 6) and the innermost winding sections (3 and 4); on the theoretical scale employed the value of the imbalance is between 3 and 4.

FIG. 9 represents the arrangement illustrated in FIG. 7 in which the previously calculated transformations were made. The winding sections 1, 3, 4, and 6 are each connected to one conductor occupying an outside position (I or VI) of minimum reactance and to one conductor occupying an innermost position (III or IV) of maximum reactance. The result is that four winding sections for which transpositions were made have the same reactance as indicated by the triangles in FIG. 9; the value of the reactance will be the average between that of the positions I and VI and that of the positions III and IV. Thus the maximum reactance imbalance z will be the difference between the value for the winding sections 2 and 5 (unchanged by the transpositions), and that of the circuits 1, 3, 4 and 6 after the transposition, which is obviously less than the value y obtained for the prior art arrangement.

8

It has thus been shown that by the practice of my invention, transpositions can be made between the winding sections of a transformer and the outgoing leads for the transformer that will reduce current and reactance imbalances in the winding circuits caused by segregation of external conductors into like-polarity groups at a location outside of the transformer. Formulas have been presented for determining the transpositions that will produce the theoretically optimum results. However, it is to be understood that my invention is not limited to transpositions solely in accord with the formulas. The invention includes arrangements in which the transpositions are not the same as those calculated as producing theoretically optimum results, since it may be advantageous in certain special situations to depart from the calculated arrangements. My invention has the advantage that it permits the use of the simple, direct connections between the heavy rigid bars employed to carry large currents obtainable in those arrangements where the conductors of like-polarity are segregated; at the same time, the reactance and current imbalances caused by this type of arrangement can be reduced to a minimum by employing the transpositions described. My invention also permits continued use of the arrangement in which internal leads of opposite polarity are placed adjacent each to reduce imbalances on the inside of the transformer enclosure.

It will be understood, of course, that while the forms of the invention herein shown and described constitute preferred embodiments of the invention, it is not intended herein to illustrate all of the equivalent forms or ramifications thereof. For example, although the invention was illustrated and described with reference to a furnace transformer, those skilled in the art will realize that the invention is also applicable to other types of electrical apparatus such as rectifier transformers. It will also be understood that the words used are words of description rather than of limitation, and that various changes may be made without departing from the spirit or scope of the invention herein disclosed, and it is aimed in the appended claims to cover all such changes as fall within the true spirit and scope of the invention.

What I claim as new and desire to secure by Letters Patent of the United States is:

1. Electrical apparatus comprising an enclosure containing a winding divided into a plurality of parallel-connected sections, the ends of the winding sections being at different instantaneous polarities during operation of said apparatus, each end of each winding section being connected to a lead that extends to the outside of said enclosure, the leads from said winding sections being connected externally of said enclosure to conductors having predetermined positions with respect to each other, the relative reactance of the external conductors in the circuit of each parallel-connected section being determined by the arrangement in which said winding sections are connected to said leads on the inside of said enclosure, the sequence of connections between said winding sections and said leads being such that adjacent leads have opposite polarities, and the leads connected to opposite ends of at least one winding section having at least one lead connected to a different winding section interleaved therebetween.

2. A transformer comprising a winding divided into more than two winding sections, the positive end of each winding section being connected to a conductor, and the negative end of each winding section being connected to a different conductor, said conductors being segregated into groups of like-polarity, said conductors being linked by leakage flux in different amounts so as to cause a reactance imbalance between conductors that varies according to the position of the conductors with respect to each other, and the connections between at least two winding sections and their associated conductors being transposed so that one conductor that has a high reactance position in its like-polarity group is connected to one end of a

winding section that has a low reactance position conductor connected to its other end.

3. A step-down transformer comprising a winding divided into more than two winding sections, an enclosure containing said winding sections, the positive end of each winding section being connected to a lead, and the negative end of each winding section being connected to a different lead, the leads from the winding sections being positioned adjacent each other and passing through said enclosure at one end of said transformer, physically adjacent leads carrying currents flowing in opposite directions, groups of conductors externally connected to the leads of like-polarity from the winding sections, said conductors being linked by different amounts of flux so as to cause a reactance imbalance between the conductors in each external group that varies according to the position of the conductors with respect to each other in their group, the connections between at least two winding sections and their associated leads being transposed so that one winding section that is connected at one end to a conductor having a high reactance position is connected at its other end to a conductor having a low reactance position.

4. A transformer comprising a winding divided into more than two winding sections, an enclosure containing said winding sections, the positive end of each winding section being connected to a lead, and the negative end of each winding section being connected to a different lead, the leads for each winding section being positioned adjacent each other and passing through said enclosure at one end of said transformer, physically adjacent leads carrying currents flowing in opposite directions, segregated groups of conductors externally connected to the leads of like-polarity of each winding section, leakage flux linking said conductors in different amounts so as to cause a reactance imbalance between the conductors in each segregated external group that varies according to the position of the conductors with respect to each other in their group, at least one conductor in each group occupying a position of maximum reactance and at least one conductor in each group occupying a position of minimum reactance, the connections between said winding sections and their associated leads being arranged so that at least one winding section is connected at one end to a conductor occupying a position of maximum reactance and is connected at its other end to a conductor occupying a position of minimum reactance.

5. A transformer comprising a winding divided into more than two winding sections, an enclosure containing said winding sections, the positive end of each winding section being connected to a lead, and the negative end of each winding section being connected to a different lead, the leads for each winding section being positioned adjacent each other and passing through said enclosure at one end of said transformer, physically adjacent leads carrying currents flowing in opposite directions, segregated groups of conductors externally connected to the leads of like-polarity from the winding sections, the conductors in each external group being positioned adjacent each other so that two conductors occupy outside positions and at least one conductor occupies an interior position between the two outside conductors, flux in different amounts linking said conductors so as to cause the conductor occupying the interior position to have a higher reactance than the conductors occupying the outside positions, the connections between said winding sections and their associated leads being arranged so that one winding section that is connected at one end to the conductor having the high reactance interior position is connected at its other end to one of the conductors having a low reactance outside position.

6. A transformer comprising a winding divided into four parallel-connected winding sections, an enclosure containing said winding sections, the positive end of each winding section being connected to a lead, and the negative

end of each winding section being connected to a different lead, the leads from each winding section being positioned adjacent each other and passing through said enclosure at one end of said transformer, physically adjacent leads carrying currents flowing in opposite directions, segregated groups of four conductors having the same length externally connected to the leads of like-polarity from each winding section, the conductors in each external group being aligned adjacent each other so that two conductors occupy outside positions and two conductors occupy interior positions between the two outside conductors, said conductors being linked by different amounts of flux so as to cause the conductors occupying the interior positions to have a higher reactance than the conductors occupying the outside positions, the connections between said winding sections and their associated leads being arranged so that each winding section that is connected at one end to a conductor having a high reactance interior position, and each winding section is connected at its other end to a conductor having a low reactance outside position.

7. A transformer comprising a winding divided into six parallel-connected winding sections, an enclosure containing said winding sections, the positive end of each winding section being connected to a lead, and the negative end of each winding section being connected to a different lead, the leads for each winding section being positioned adjacent each other and passing through said enclosure at one end of said transformer, physically adjacent leads carrying currents flowing in opposite directions, segregated groups of six conductors having the same length externally connected to the leads of like-polarity of each winding section, the conductors in each external group being aligned adjacent each other so that two conductors occupy outside positions, two conductors occupy intermediate positions between the outside conductors, and two conductors occupy interior positions between the conductors occupying intermediate positions, flux in different amounts linking said conductors so as to cause the conductors occupying the interior positions to have the highest reactance and the conductors occupying the outside positions to have the least reactance while the conductors occupying the intermediate positions have an intermediate reactance, the connections between said winding sections and their associated leads being arranged so that two winding sections are each connected at one end to conductors having a high reactance interior position and each of said two winding sections is connected at its other end to a conductor having a low reactance outside position.

8. Electrical apparatus comprising a current producing winding divided into an odd number greater than 1 of parallel-connected sections, during operation of said apparatus the opposite ends of each winding section having different instantaneous polarities, each end of each winding section being connected to a different lead, said winding sections being arranged adjacent each other in a predetermined first sequence with the winding section at one end of said first sequence being assigned the number 1 and the remaining winding sections being numbered consecutively therefrom, said leads being arranged adjacent each other in a predetermined second sequence with the lead of one polarity at one end of said second sequence being assigned the number 1 and the remaining leads of the same polarity being numbered consecutively therefrom, and the numbers designating the winding sections and the numbers designating the leads that are connected to each other for said one polarity being determined by the following formulas:

$$\left(\frac{n+3}{2}-a\right) \text{ is connected to } (a)$$

and

$$\left(\frac{n+1}{2}+a\right) \text{ is connected to } (n+1-a)$$

11
or

$\left(\frac{n+1}{2}-a\right)$ is connected to (a),

and

$\left(\frac{n-1}{2}+a\right)$ is connected to $(n+1-a)$

where "n" is the number of winding sections, and when

$$\left(\frac{n+1}{4}\right)$$

is a whole number, "a" is evaluated for 1, 2, 3, etc. up to

$$\left(\frac{n+1}{4}\right)$$

but when

$$\left(\frac{n+1}{4}\right)$$

is not a whole number, "a" is evaluated for 1, 2, 3, etc. up to

$$\left(\frac{n+3}{4}\right)$$

9. Electrical apparatus comprising a current producing winding divided into an even number greater than 2 of parallel-connected sections, during operation of said apparatus the opposite ends of each winding section having different instantaneous polarities, each end of each winding section being connected to a different lead, said winding sections being arranged adjacent each other in a predetermined first sequence with the winding section at one end of said first sequence being assigned the number 1 and the remaining winding sections being numbered consecutively therefrom, said leads being arranged adjacent each other in a predetermined second sequence with the lead of one polarity at one end of said second sequence

12

being assigned the number 1 and the remaining leads of the same polarity being numbered consecutively therefrom, and the numbers designating the winding sections and the numbers designating the leads that are connected to each other for said one polarity being determined by the following formulas:

$\left(\frac{n+2}{2}-a\right)$ is connected to (a)

and

$\left(\frac{n}{2}+a\right)$ is connected to $(n+1-a)$

where "n" is the number of winding sections, and when

$$\frac{n}{2}$$

is an even number, "a" is evaluated for 1, 2, 3, etc. up to

$$\frac{n}{4}$$

but when

$$\frac{n}{2}$$

is an odd number, "a" is evaluated for 1, 2, 3, etc. up to

$$\frac{n+2}{4}$$

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