United States Patent

Lys

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[54] **ANTI-HARMONIC TRANSFORMER**

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[30] **Foreign Application Priority Data**

Jan. 19, 1970 France....................................7001717

[52] **U.S. Cl.**..**336/5,** 321/57, 321/68, 323/48, 323/91, 336/12, 336/180

[51] **Int. Cl.**..**H01f 33/00**

[58] **Field of Search**..................336/5, 10, 12, 170, 171, 180; 323/91, 48; 321/57, 58

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Attorney—Waters, Roditi, Schwartz & Nissen

[57] **ABSTRACT**

Devices for eliminating in a three-phase voltage transformer T, separating two networks A and B the voltage harmonics preexisting within the three phase voltage feeding A and detrimental to B, or the current harmonics generated by B and detrimental to A. The devices include single phase transformers, the primary windings of which are "delta" coupled and the secondary windings of which are "star" coupled, the angles determined by the legs of the triangles and of the stars exhibiting unique values, together with single phase autotransformers for connection to the A and B networks. When eliminating only current harmonics, T need only be constituted of two single phase transformers the primary secondary windings of which are in quadrature together with single phase transformers, the windings of which are connected to specific current taps provided on the above-mentioned transformers. They can be used in installations for electrochemistry, electrometallurgy, power distribution of d.c. current and for installations of static power conversion.

6 Claims, 11 Drawing Figures

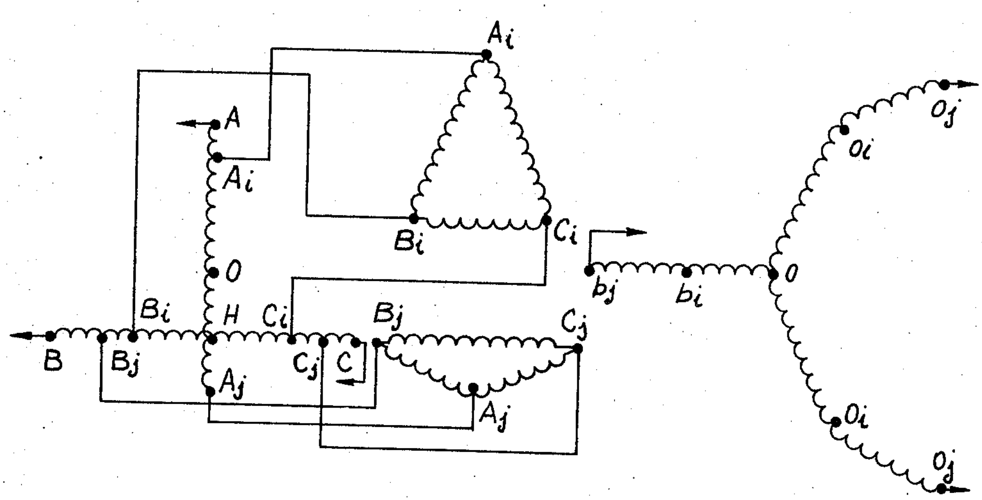


FIG. 1

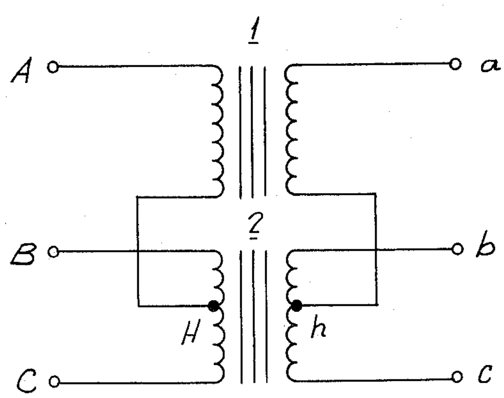


FIG. 2

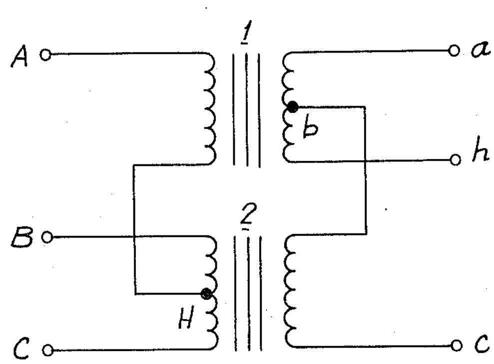


FIG. 3

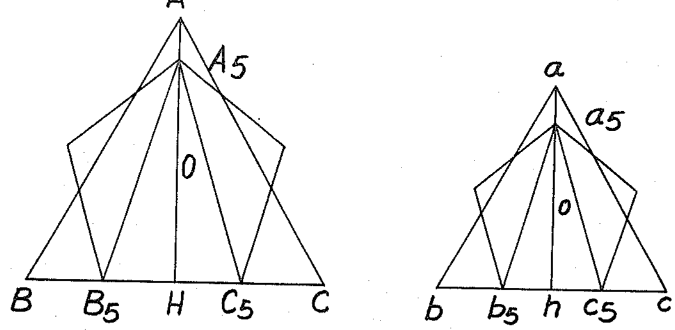


FIG. 4

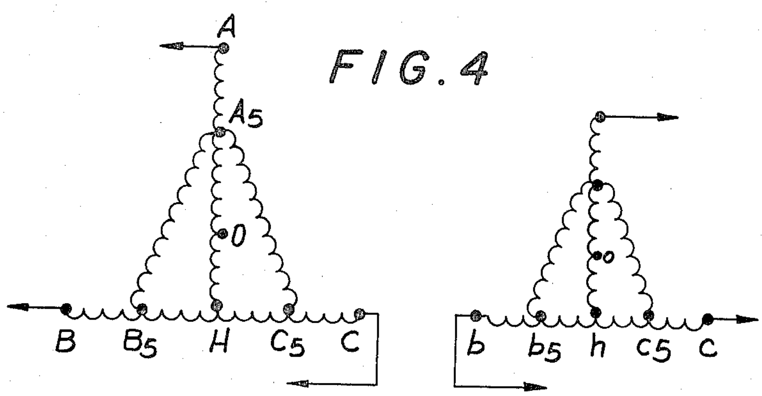


FIG. 5

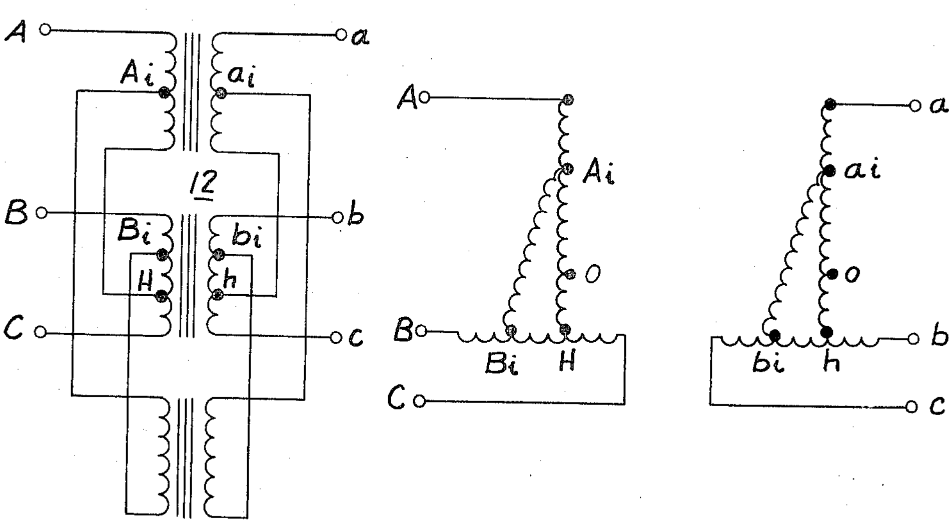


FIG. 6

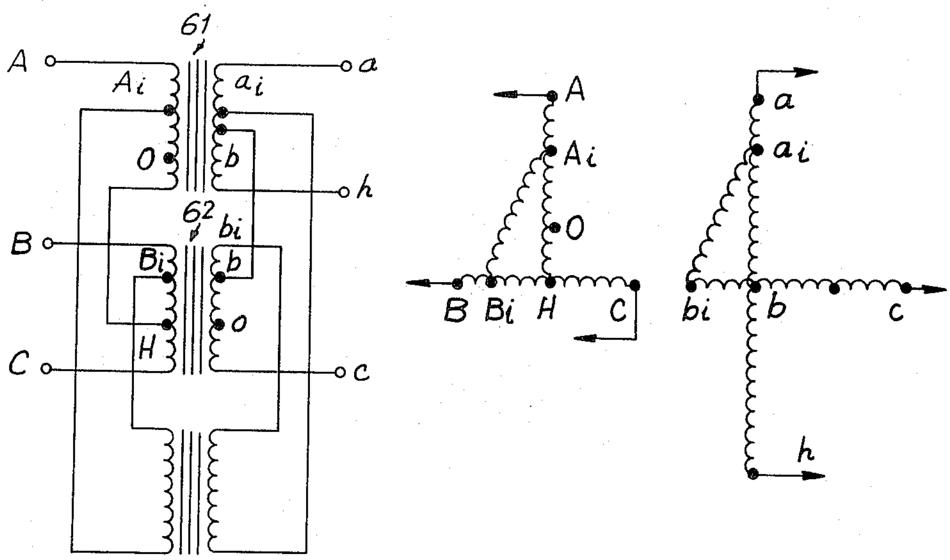


FIG. 7

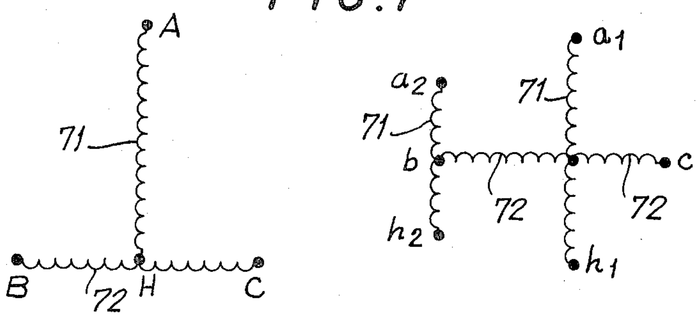


FIG. 8

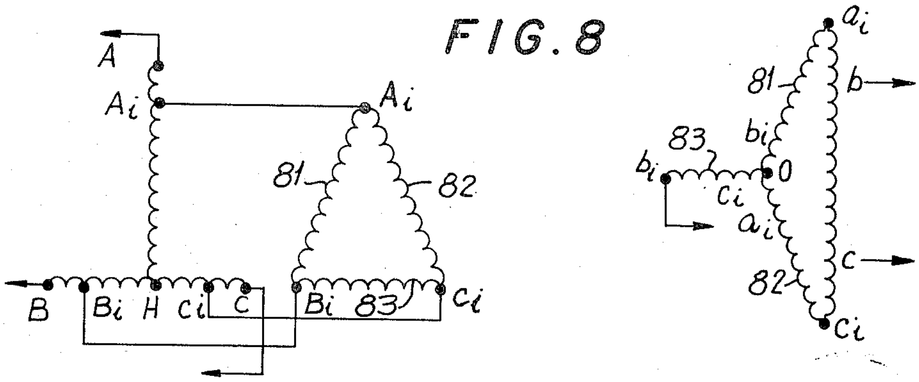


FIG. 9

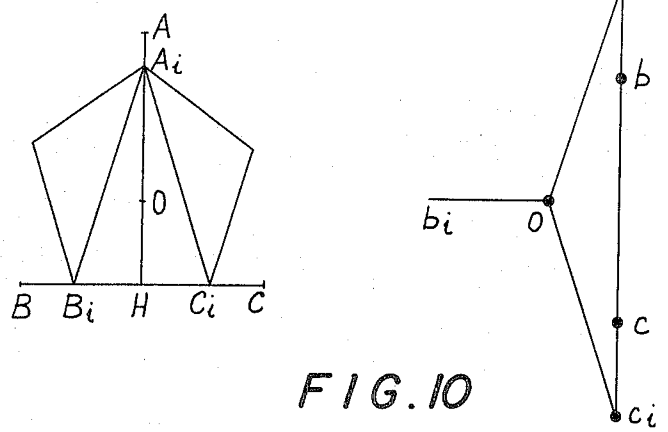


FIG. 10

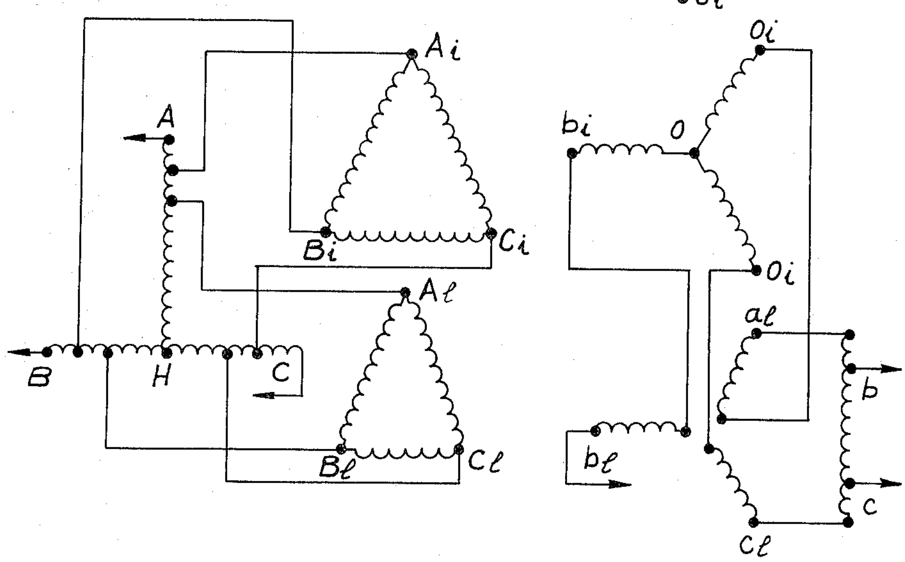
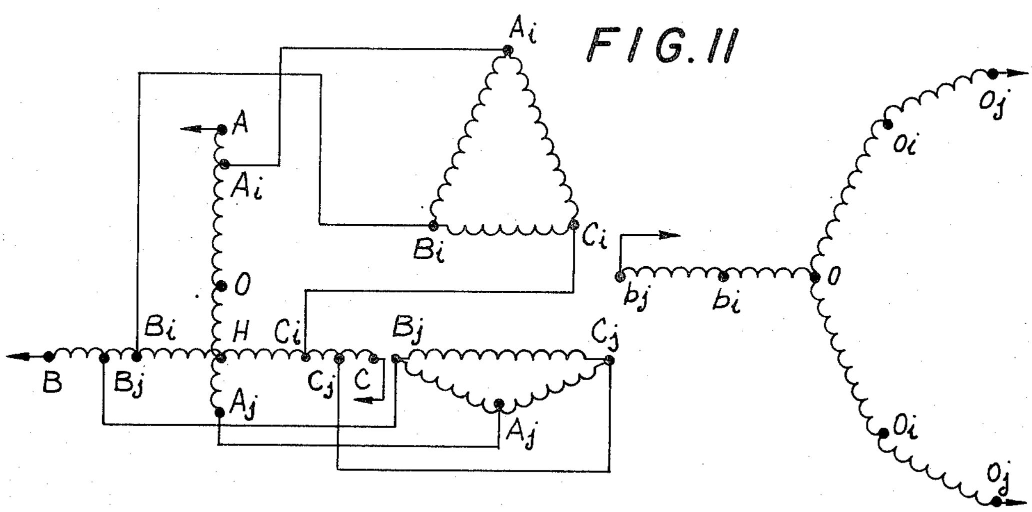


FIG. 11



ANTI-HARMONIC TRANSFORMER

BACKGROUND OF THE INVENTION

The present invention relates to polyphase voltage transformers for removing voltage and current harmonics from electrical networks which are connected by the transformers. For example, if the transformer separates a first from a second network with the power passing from the first to the second, it can protect the second network from the harmonics existing in the first network. Similarly, if the second network includes nonlinear elements which generate current harmonics, the present invention prevents such harmonics from being transferred to the first network.

In industrial practice, electrical polyphase voltage transformers are conventionally provided with "symmetrical" windings whether or not they include single phase elements with independent circuits and star or polygon coupled electrical circuits, or include windings arranged on a single magnetic circuit with free or forced flux. They generally include a primary winding and a secondary winding for which are used conventional connection arrangements such as "star", "-delta", "mesh" and so forth.

Depending upon the connection arrangements selected for the three-phase transformers, the third harmonics and their multiple can normally be eliminated. For instance, if both the primary and secondary windings are star coupled and their respective neutral points insulated, the flux components produced by current third harmonics and their multiple are prevented from circulating. Moreover, if for example the secondary winding is delta coupled, the electromotive force includes a frequency three times as high as the fundamental and generates in the delta circuit a current whose frequency is also triple, which almost completely suppresses the third harmonic and supplies the necessary ampere-turns for a correct compensation of the flux within the magnetic cores, whether the transformers are free or forced flux types.

This latter property is, furthermore, used more particularly for "star-star" coupled large transformers with delta arranged tertiary windings.

Therefore, in most cases only the third harmonics and their multiple are eliminated through the above mentioned conventional couplings.

SUMMARY OF THE INVENTION

An object of the invention is to provide an improved apparatus for eliminating harmonics in single and polyphase transformers.

The devices according to the invention eliminate harmonics of all kind without restricting such elimination to third harmonics and their multiple. These devices are of two types: those related to the devices for eliminating current harmonics generated by nonlinear network impedances fed back to the power supply and those related to the devices for eliminating both the voltage harmonics generated by the power supply for the network it feeds or the current harmonics generated by the lack of linearity of the network impedances.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGS. 1 and 2 are schematic diagrams of transformer couplings in accordance with this invention;

FIG. 3 is a geometric representation of the relationship between windings determined in accordance with this invention;

FIG. 4 is a schematic diagram of transformer windings geometrically arranged in accordance with this invention;

FIGS. 5 through 8 are schematic diagrams of geometric arrangements of transformers connected in accordance with this invention;

FIG. 9 is a geometric representation of the relationship between windings for eliminating voltage and current harmonics in accordance with the principles of this invention; and

FIGS. 10 and 11 are schematic diagrams of yet other windings geometrically arranged to eliminate voltage and current harmonics.

DETAILED DESCRIPTION

With respect to the first above mentioned type, the present invention embodies with a three-phase system, a transformer T made of two single phase transformers 1 and 2 the primary and secondary windings of which are electrically intercoupled in a "quadrature" (see FIGS. 1 and 2).

The "quadrature" coupling hereafter referred to is actually the coupling characterizing the three phase windings of the so-called "Scott" configuration, one of the windings having $\sqrt{3/2}$ times less winding turns than the other, and one of its ends being connected to the middle point of the other, both thus including the altitude and the base of an equilateral triangle, according to the classical conventional representation.

This "quadrature" coupling for the couplings 1 and 2 has two possible arrangements: in the first, both transformers 1 and 2 have the same transformation ratio β equal to the transformation ratio of T; in the second, the transformers respectively have for a transformation

$$\beta_1=\beta\frac{\sqrt{3}}{2}$$

$$\beta_2=\frac{2}{\sqrt{3}}\beta$$

β being the transformation ratio of T.

Transformers 1 and 2 are provided with intermediary current taps H and h on their respective windings and, between these taps, "filtering" transformers are provided.

According to FIG. 3 (related to the arrangement of FIG. 1), the triangles ABC and abc have centers O and o which stand for the primary and secondary voltage triangles and their respective origins, two regular pentagonal contours centered in O and *o* can be formed having particular vertices A_5, B_5, C_5, and a_5, b_5, c_5. These vertices are precisely carried by AH and BC for the first and by *ah* and *bc* for the second transformer.

In accordance with transformer theory, the voltages across the terminals of a winding or part of it can be shown as the voltage diagram of the transformer and, similarly the segments shown as the diagram of voltages may represent the windings or part of windings at the terminals of which the voltages represented by these segments can be recovered.

Segments A_5B_5, A_5C_5, a_5b_5, a_5c_5, which are seen in FIG. 3, represent the windings of the single phase transformers linking the unique points A_5, B_5, C_5, a_5, b_5, c_5.

FIG. 4 is a diagrammatical representation of the device after both transformers have been arranged, the primary and secondary windings respectively connecting the unique taps bearing subscript 5. If a system of three phase sinuoidal voltages is applied to ABC, a system of voltages which are also three phase and sinuoidal will appear at abc; if moreover, the network fed in abc includes nonlinear impedances (rectifiers, thyristors or the like) the feeding currents will comprise, apart from the fundamental harmonics, all orders and, particularly, the fifth harmonics and their multiples.

The wound circuits $A_5B_5C_5$ and $a_5b_5c_5$, taking into consideration the unique points or positions of the tap of subscript 5, have the property of only including, so far as currents with a frequency of five times the fundamental frequency is concerned, homopolar currents which are phase equal currents to which the impedance presented by $A_5B_5C_5$ and $a_5b_5c_5$ is very low.

In other terms, the presence of the "filtering" transformers (A5B5 – *a5b5*) and (A5C5 – *a5c5*) removes from the network the current harmonics of fifth order and their multiples. It is to be noted that removing a single phase transformer as (A5C5 – *a5c5*) does not change the result so that the fifth harmonic which is sought to be eliminated can be completely suppressed by a single phase transformer with primary A_5B_5 and secondary a_5b_5.

This result which has been shown for the fifth current harmonic can be extended to any harmonic of sequence *i* (*i* - odd), the foregoing description applying to pentagonal contours and being applied to the polygonal regular contours having i sides, respectively centered in O and o, two vertices of which are respectively carried by the sides BC and bc of the triangles ABC and abc and a third vertex of which is itself located respectively on the segment AH and on the segment *ah*.

In other terms, the current harmonic of sequence i can be removed by embodying — according to FIG. 5 — a filtering single phase transformer (A_iB_i - a_ib_i), respectively, at the level of the primary and secondary windings of the transformers **11** and **12**, between the intermediary taps A_i, B_i, a_i, b_i, the positions of which on the associated primary and secondary voltage diagrams are such that $OA_i = OB_i$, $oa_i = ob_i$ and the angles formed by OA_i and OB_i and oa_i and ob_i are equal to a whole number of $2\ \pi/i$ radians. This condition can be written in accordance with the following expressions:

$$\frac{HA_i}{HA}=\frac{ha_i}{ha}=\frac{1}{3}\left(1+\frac{1}{\cos\ (2k+1)\frac{\pi}{i}}\right)$$

in which k is a whole number or null

$$\frac{HB_i}{HB}=\frac{hb_i}{hb}=\frac{1}{\sqrt{3}}tg(k+1)\frac{\pi}{i}$$

The geometrical segments thus outlined represent for the same coil the number of turns of the winding sections they stand for.

Using $k = 0$, these expressions lead to a simple solution, viz.:

$$\frac{HA_i}{HA}=\frac{ha_i}{ha}=\frac{1}{3}\left(1+\frac{1}{\cos\ \pi/i}\right)$$

$$\frac{HB_i}{HB}=\frac{hb_i}{hb}=\frac{1}{\sqrt{3}}tg\pi/i$$

and without hindering the efficiency of the apparatus the presentation with $k = 0$ is more simple. *tg* is the trigonometric tangent.

Applying the same type of mathematical approach for the arrangement shown in FIG. 2 also allows removing current harmonics of sequence i. In fact, the transformer ($A_iB_i - a_ib_i$) is arranged according to FIG. 6 between the taps A_iB_i at the primary and a_ib_i at the secondary winding; the tap b_i extending from the winding b_o and the taps A_i, B_i, a_i, b_i, being so arranged that the triangles $A_iB_iH_i$ and $a_ib_ih_i$, with center o, are geometrically similar and that oa_i is equal to ob_i, it is possible under the same conditions as above to remove the harmonics of sequence i.

More specifically, the current taps A_i, B_i, a_i, b_i between which the filtering transformer (A_iB_i - a_ib_i) is arranged are such (according to FIG. 6) that:

$$\frac{HA_i}{HA}=\frac{1}{3}\left(1+\frac{1}{\cos\ (2k+1)\pi/i}\right)$$

k being a whole number or null

$$\frac{HB_i}{HB}=\frac{ba_i}{ba}=\frac{1}{\sqrt{3}}tg(2k+1)\pi/i$$

$$\frac{HB_i}{Ha_i}=\frac{bb_i}{ba_i}$$

The geometrical segments thus outlined also represent for one and the same coil the number of turns of the winding sections they stand for.

Applying $k = 0$ in these expressions also leads to a simple solution, viz.:

$$\frac{HA_i}{Ha}=\frac{1}{3}\left(1+\frac{1}{\cos\ \pi/i}\right)$$

$$\frac{HB_i}{HB}=\frac{ba_i}{ba}=\frac{1}{\sqrt{3}}tg\pi/i$$

$$\frac{HB_i}{HA_i}=\frac{bb_i}{ba_i}$$

Without hampering the efficiency of the device, the representation of it is thus simplified.

One may note that the arrangements shown at FIGS. 5 and 6 extend to the harmonic of sequence i, the above mentioned property characterizing the delta coupled windings of conventional three phase transformers with respect to eliminating third order current harmonics and their multiple.

The "anti-current harmonics" three phase transformer is thus characterized by the assembly of the two transformers **11–12** and **61 –62** and the associated single phase transformers ($A_iB_i - a_ib_i$) as described hereabove.

This will eliminate all current harmonics of any sequence (generally odd) liable to be generated by nonlinear impedances fed from the network.

A balanced three-phase system is liable to cause the appearance of current harmonics of sequences 3,5,7,11,13,17,19, etc. each one susceptible to being eliminated by the method hereabove described. However, in order to embody the smallest possible number of single phase transformers one can limit the same, although sometimes with a slight efficiency drop of the device, to eliminate harmonics by units of 2. For instance the 5th and 7th harmonics can be substantially reduced through the embodiment of a single transformer ($A_6B_6 - a_6b_6$) linking the taps A_6, B_6, a_6, b_6, such as:

$$\frac{HA_6}{HA}=\frac{ha_6}{ha}=\frac{1}{3}\left(1+\frac{1}{\cos\ \pi/6}\right)=\frac{\sqrt{3}+2}{3\sqrt{3}}$$

according to the arrangement of FIG. 5

$$\frac{HB_6}{HB}=\frac{hb_6}{hb}=\frac{1}{\sqrt{3}}tg\pi/6=1/3$$

or such as:

$$\frac{HA_6}{HA}=\frac{1}{3}\left(1+\frac{1}{\cos\ \pi/6}\right)=\frac{\sqrt{3}+2}{3\sqrt{3}}$$

according to the arrangement of FIG. 6

$$\frac{HB_6}{HB}=\frac{ba_6}{ba}=\frac{1}{\sqrt{3}}tg\,\mu/6=1/3$$

$$\frac{HB_6}{HA_6}=\frac{bb_6}{ba_6}$$

in replacement for the two transformers (A_5B_5 - a_5b_5) and ($A_7B_7 - a_7b_7$) theoretically required.

Similarly, the harmonics 11 and 13 could be substantially eliminated by the use of a single phase transformer linking the taps having the subscript 12, harmonics 17 and 19 being in turn eliminated by a single phase transformer of subscript 18 and so on.

Furthermore, for instance, harmonics 13 and 17 could be damped by a transformer linking the taps of subscript 15.

Thus, and generally speaking, two harmonics following one another could be eliminated through a single phase transformer the subscript of which is equal to half the sequence sum of these harmonics.

It is obvious that this invention may apply to any polyphase system and is not restricted to three-phase systems; in particular, when the "anti-current harmonic" transformer also multiplies the number of phases.

FIG. 7 illustrates this property showing the transformation of a conventional classical three phase system to a five-phase system: the transformer **71** comprises three windings, viz.: AH at the primary, a_1h_1 and a_2h_2 at the secondary; the transformer **72** comprises two windings, viz.: BC at the primary and *bc* at the secondary. Embodying suitable single phase transformers across the taps at the unique positions, according to the same principles as above outlined, allows eliminating current harmonics the number and the importance of which are reduced by the increase in the number of phases.

Lastly, the method also suits the "teritiary" windings of power transformers if the components of the main windings (primary and secondary) of these transformers are similar to that characterizing the above-mentioned T transformer composed of single phase windings respectively arranged in quadrature. It is possible to utilize tertiary type windings wound as the above mentioned transformers **71** and **72** on the same magnetic circuits as the preceding ones and on which intermediary taps of the A_iB_i and a_ib_i types are also provided; single phase transformers ($A_iB_i - a_ib_i$) link these taps in order to eliminate the current harmonics of sequence *i*, this arrangement constituting an extension of the principle of the transformers provided with three windings, one of which is delta arranged with a view toward eliminating harmonic 3.

The devices according to the second category set forth at the beginning of the description enable voltage and current harmonics of any *i* sequence to be eliminated. They embody three single phase transformers, as shown in FIG. **8**, transformers which are **81**, **82** and **83**.

The transformer **81** is formed by a primary A_iB_i and a secondary a_ib_i. The transformer **82** is formed by a primary A_iC_i and a secondary a_ic_i. The transformer **83** is formed by a primary B_iC_i and secondary b_ic_i.

The primary windings are delta coupled (dissymetrical) and the secondary are star coupled (also dissymetrical), with center **0**. Feeding the primary windings $A_iB_iC_i$ occurs through autotransformers AH and BC which are themselves power supplied in A, B, C. Intermediary taps are provided on these autotransformers the position of which are such that:

$$\frac{\overline{HA_i}}{\overline{Ha}}=\frac{1}{3}\left(1+\frac{1}{\cos\ (2k+1)\ \pi/i}\right)$$

$$\frac{\overline{HB_i}}{\overline{HB}}=\frac{\overline{HC_i}}{\overline{HC}}=\frac{1}{\sqrt{3}}tg(2k+1)\ \pi/i$$

In these expressions *k* is a whole number or null and the outlined geometrical segments also characterize the modulus of the corresponding composite voltages.

The secondary windings are star coupled at **0** and the end sections a_ic_i of the star are, according to FIG. **8**, connected by a single phase transformer a_ic_i; intermediary current taps *b* and *c* are provided on this autotransformer so that the end section b_i of the star and the points *b* and *c* form an equilateral triangle, the center **0** of which is the same as that of the triangle $a_ib_ic_i$. Similarly to the features of the devices described with relation to the first category, A_i, B_i, and C_i represent the voltages at the diagram of FIG. **9** and, with relation to FIG. **8**, the 3 particular vertices of a regular polygon having *i* sides centered in **0**. The transformation ratios of transformers **81**, **82** and **83** are:

$$\frac{\overline{ob_i}}{\overline{B_iC_i}}=\frac{\overline{oc_i}}{\overline{C_iA_i}}=\frac{\overline{oa_i}}{\overline{A_iB_i}}$$

as illustrated in FIG. **9**.

The arrangement thus described is such that if the supply three phase voltage at A, B, C has a harmonic of sequence *i*, the current harmonics of sequence *i* carried by the primary windings of transformers **81**, **82** and **83** are homopolar, this meaning that they are equal and respectively in phase. Consequently, the harmonic three phase voltages of rank *i* at the secondary winding of transformers **81**, **82** and **83** are in phase and those respectively available at the secondary winding of transformers **81**, **82** and **83** are in phase and those respectively available at b_i, *b* and *c* are equal with respect to modulus and phase. The composite voltages available across b_i, *b*, *c* at the secondary winding are consequently free from any harmonic of rank *i*.

The present apparatus is reversible, this meaning that fed with a three-phase voltage at b_i, *b*, *c* it will also exhibit at A, B, C a three-phase voltage free from any harmonics of rank *i*. Lastly, this arrangement can filter current harmonics of rank *i* in the same way as the devices of the above described first category.

Should several harmonics of the feeding voltage with ranks *i*, *j* . . . *l* have to be eliminated, the above described arrangements for eliminating the harmonic *i* are applied one after the other and a "series" arrangement is embodied which is characterized as follows:

Each harmonic can be eliminated through a set of three single phase transformers **81**, **82** and **83**, fed through adequate taps provided on the autotransformers AH and BC.

The secondary windings such as ca_i are series connected so as, one with the others the secondary windings such as oc_i and also the secondary windings such as ob_i. In that way, the primary windings of the type A_iB_i are "parallel" arranged across the taps of the type A_iB_i set on AH and BC whereas the secondary windings of the type ob_i are series arranged in conformity with FIG. **10**; a single phase autotransformer is inserted between the end taps *a* and *c* of the secondary winding, and this single phase autotransformer is provided with intermediary current taps *b* and *c* in the same position as set forth above.

Consequently the three phase voltage available across the terminals b_i, *b*, *c* is free from the harmonics of rank *i*, *j* . . . *l* that were to be eliminated.

This "series" arrangement is likewise reversible and embodies 3*n* single phase transformers and three single phase autotransformers, *n* being the number of harmonics of odd rank and of prime numbers with relation one to the other that were to be eliminated.

It is possible to simplfy the device by noting in FIG. **11** that the secondary current taps *b* and *c* can merge with the end taps a_j and c_j, provided certain conditions are met: this will happen if certain current taps of the type A_j are utilized exterior to the segment AH (see Fig. **11**) so that the voltage triangle $A_jB_jC_j$ exhibits an obtuse angle greater than 2 π/3 radians. Under such conditions, adequate transformation ratios can be selected and polygons oc_ic_j and oa_ia_j can be built with the angle c_joa_j (FIG. **11**) precisely equal to 2 π/3 radians.

The devices according to the first category can be used for all polyphase networks(generally three-phase) which have to be protected from the influence of current harmonics. This influence from harmonics is always a drawback and often causes power losses through eddy current, overheating, resonances and overvoltages, operation instability, radioelectrical disturbances and so forth. Apart from particular cases where eliminating a harmonic of any determined sequence is the main object, it should be noted that the "anti-current harmonic" transformer can be used with or without conversion of the number of phases before rectifiers and power thyristors: the current harmonics that the latter often generate are detrimental in a general way to the network through which they are fed. This is the case for certain installations such as batteries charging, traction, electrochemistery, electrometallurgy, power supply for radio transmitters, power distribution through high voltage d.c. current, and so forth.

The devices according to the second category can eliminate voltage and current harmonics. The "anti-harmonics" transformers thus defined are not only used for the application above-mentioned, but may also be used after certain generators supplying a periodical wave which is not purely sinuoidal such as inverters and static cycloconverters, particularly when those apparatus are "assisted," that is when they feed an already existing network which commands frequency and voltage form.

What is claimed is:

1. Apparatus for eliminating harmonics comprising a transformer coupling a first network to a second network, said transformer comprising two single phase transformers including respective primary windings connected in quadrature and respective secondary windings connected in quadrature, said primary windings being electrically connected together by connecting one end of one of said primary windings to a tap point on the other of said respective primary winding, said secondary windings each being electrically connected to a tap point on the other of said respective secondary windings, said tap points being located at the midpoints of said other of said respective primary and secondary windings, said primary windings having 3/2 times the number of turns of said respective secondary windings, said primary and secondary windings being provided with intermediary taps designated A_i and B_i on said primary windings and a_i and b_i on said secondary windings, the subscript *i* representing the odd harmonic to be eliminated, the positions of said taps being defined as:

$$\frac{HA_i}{Ha}=\frac{ha_i}{ha}=\frac{1}{3}\left(1+\frac{1}{\cos\,(2k+1\ \pi/i)}\right)$$

$$\frac{HB_i}{HB}=\frac{hb_i}{hb}=\frac{1}{\sqrt{3}}tg(2k+1)\ \pi/i$$

wherein k is a whole number or null and the designated geometrical segments represent the number of associated winding turns and H and h are the midpoint taps of said respective primary and secondary windings; and two further single phase transformers including primary and secondary windings and having a transformation ratio β, the primary windings and secondary windings of said two further single phase transformers being arranged across the taps A_i and B_i, and a_i and b_i respectively.

2. Apparatus according to claim 1 wherein said apparatus comprises a three phase transformer having a transformation ratio β comprising two single phase transformers electrically coupled together, the respective primary windings of said single phase transformers being electrically connected together by connecting one end of said primary of one of said single phase transformers to the midpoint of the other primary, said midpoint being designated as H, the respective secondary windings of said single phase transformers being electrically coupled together by connecting one end of the secondary of the other of said single phase transformers to the midpoint of the secondary of said one of said single phase transformers, said latter midpoint being designated h, N_1 and n_1 designating the number of winding turns of the primary and secondary windings of said one of said single phase transformers and N_2 and n_2 the number of winding turns of the primary and secondary windings of said other of said single phase transformers, the transformation ratios β_1 and β_2 if said single phase transformers being:

$$\beta_1=\frac{N_1}{n_1}=\beta\frac{\sqrt{3}}{2}$$

$$\beta_2=\frac{N_2}{n_1}=\frac{2\beta}{\sqrt{3}}$$

$$\frac{HA_i}{Ha}=\frac{1}{3}\left(1\frac{1}{\cos\ (2k+1)\pi/i}\right)$$

$$\frac{HB_i}{HB}=\frac{ba_i}{ba}=\frac{1}{\sqrt{3}}\ \text{tg}\ (2k+1)\pi/1$$

$$\frac{HB_i}{HA_i}=\frac{bb_i}{ba_i}$$

wherein k has simultaneously the same value and in which the designated geometrical segments represent winding parts and for one same coil the number of winding turns of the winding portions they stand for; the primary and secondary windings of at least one of said further single phase transformers having a transformation ration of

$$\frac{\beta}{\sin\ (2k+1)\pi/i}\ (1+\cos\ (2k+1)\pi/i$$

3. Apparatus according to claim 1 wherein the parameter k is null and the subscript i is equal to half the sequence sum of the two following harmonics which are to be eliminated.

4. Apparatus according to claim 2 wherein the parameter k is null and the subscript i is equal to half the sequence sum of the two following harmonics to be eliminated.

5. Apparatus for eliminating harmonics comprising (a) first and second autotransformers respectively designated AH and BC, said autotransformers being electrically connected together with a connection of one end of autotransformer AH to the midpoint H of the second autotransformer BC, a current tap A_i on said autotransformer AH, a pair of current taps B_i and C_i on said autotransformer BC, (b) three single phase transformers including primary windings designated A_iB_i, B_iC_i, and C_iA_i , current taps A_i, B_i, C_i being coupled in accordance with the following relationship:

$$\frac{HA_i}{HA}=\frac{1}{3}\left(1+\frac{1}{\cos\ (2k+1)\pi/i}\right)$$

$$\frac{HB_i}{HB}=\frac{HC_i}{HC}=\frac{1}{\sqrt{3}}\ \text{tg}\ (2k+1)\pi/i$$

wherein k is a whose number or null and in which the designated geometrical segments represents the number of turns of the associated winding sections, the secondary windings of said single phase transformer being designated a_ib_i , b_ic_i and c_ia_i and respectively conforming to the following relationship:

$$\frac{a_ib_i}{A_iB_i}=\frac{b_ic_i}{B_iC_i}=\frac{c_ia_i}{C_iA_i}$$

and being coupled in a star configuration, (c) a further single phase autotransformer a_ic_i including intermediary current taps b and c for connecting the second network.

6. Apparatus for eliminating harmonics as claimed in claim 5 comprising $3n$ single phase transformers for eliminating n harmonics of order $i, j \ldots l$, said $3n$ single phase transformers being series connected to said three single phase autotransformers.

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