United States Patent [19]

Goodman

[11] **3,845,437**

[45] **Oct. 29, 1974**

[54] **SERIES-MULTIPLE TRANSFORMER HAVING NON-INTEGER SERIES-PARALLEL VOLTAGE RATIO**

[75] Inventor: **Ernest A. Goodman,** Pittsburgh, Pa.

[73] Assignee: **Allis-Chalmers Corporation,** Milwaukee, Wis.

[22] Filed: **May 17, 1973**

[21] Appl. No.: **361,257**

[52] **U.S. Cl.** **336/147,** 323/49

[51] **Int. Cl.** **H01f 21/00**

[58] **Field of Search** 336/145, 146, 147; 323/49, 323/48

[56] **References Cited**

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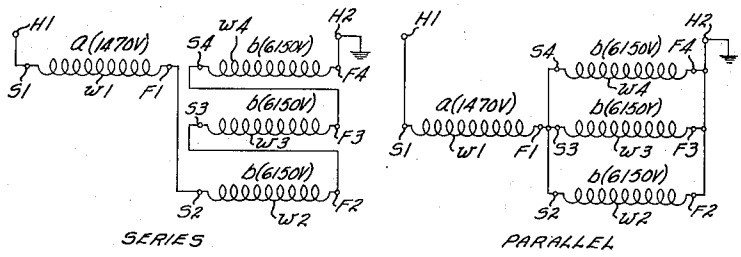
Primary Examiner—Thomas J. Kozma

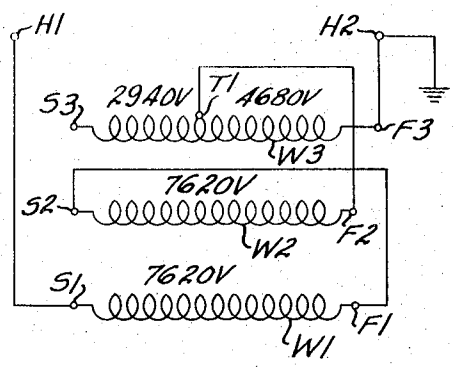
Attorney, Agent, or Firm—Lee H. Kaiser

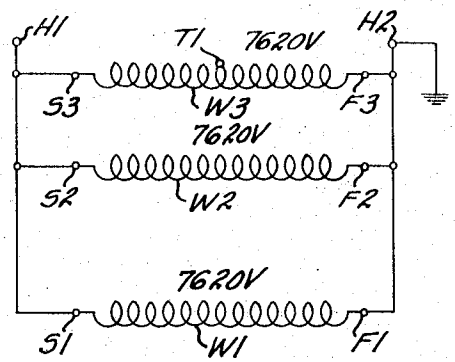
[57] **ABSTRACT**

A dual-voltage series-multiple transformer having a non-integer series-parallel voltage ratio has a plurality of untapped series-multiple primary winding sections of equal voltage rating that may be alternately connected in series or parallel and a common untapped primary winding section which is in series with the series-multiple primary winding sections in both the series and the parallel connection, thereby eliminating floating and open end windings.

7 Claims, 5 Drawing Figures



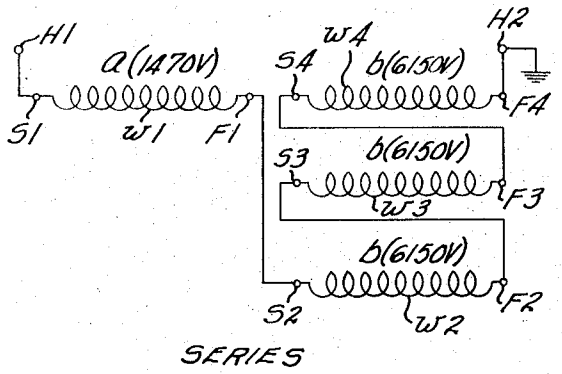




PRIOR ART

Fig. 1a

Fig. 1b



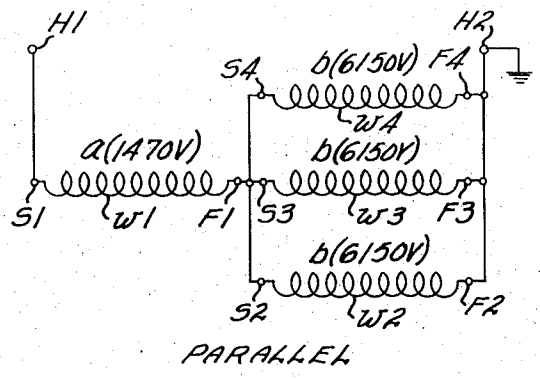


Fig. 3a

Fig. 3b

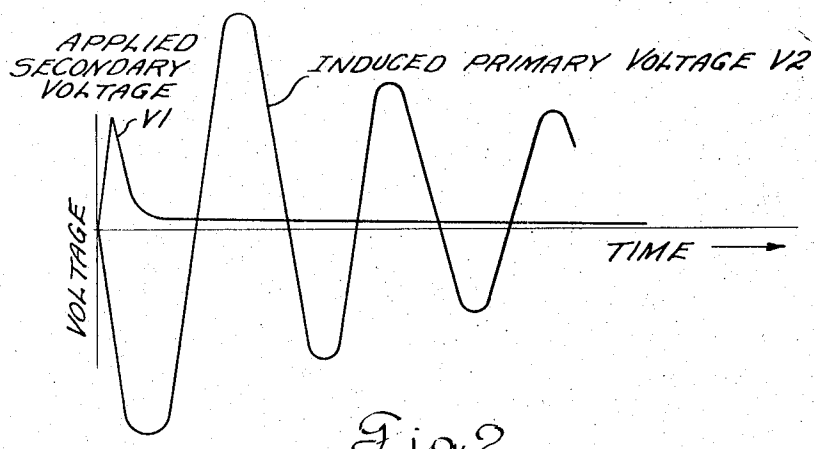


Fig. 2

SERIES-MULTIPLE TRANSFORMER HAVING NON-INTEGER SERIES-PARALLEL VOLTAGE RATIO

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to series-multiple transformers having dual voltage ratings.

2. Description of the Prior Art

It is known to provide a series-multiple transformer having a dual voltage rating which is obtained by connecting primary winding sections in either series to provide a higher primary voltage rating or in parallel to provide a lower primary voltage rating. Dual voltage rating transformers are also known wherein the higher primary voltage rating is not an integer of the lower primary voltage rating which is accomplished by connecting one primary winding section to a tap on another primary winding section in the series position. However, this non-integer arrangement leaves one end of the tapped primary winding section open, or "floating."

In a distribution transformer with a relatively high primary voltage, a substantial surge and a series of oscillations are generated in the high voltage winding when a surge exists in the secondary winding. In a non-integer series multiple winding arrangement with a floating and open winding end, such surge and oscillations in the primary (resulting from a surge in the secondary) can become extremely high and result in failure of the transformer winding and/or of the series-multiple switch.

Known dual voltage transformers having non-integer series-parallel votage ratios require graded "line end" insulation in each of the primary winding sections. Further, it is impossible to design an electrically balanced coil for such a prior art dual voltage transformer, and consequently such transformers have relatively low short circuit strength.

It is an object of the invention to provide a series-multiple transformer having a non-integer series-parallel voltage ratio wherein the primary winding is not subjected to extremely high voltage surges and oscillations when lightning currents enter the transformer through the secondary terminals.

Another object of the invention is to provide a dual voltage rating transformer wherein the higher and lower primary voltage ratings are not exact multiples and none of the primary winding sections have a floating and open end in either the series or the parallel position, thus avoiding reflected voltage oscillations when surge voltages are applied either to the secondary or to the primary windings.

A further object is to provide an improved dual voltage rating transformer having a non-integer series-parallel voltage ratio in which open end windings are eliminated and which has substantially greater short circuit strength than known series-multiple transformers having non-integer series-parallel voltage ratios.

Still another object is to provide such a dual voltage rating transformer having a non-integer series-parallel voltage ratio wherein increased insulation is only required at the line end of one primary winding section.

SUMMARY OF THE INVENTION

In accordance with the invention a dual voltage transformer has a primary winding comprising a plurality n of untapped series-multiple primary winding sections of equal voltage rating b and a common untapped primary winding section having a voltage rating a different than that of each of the series-multiple primary winding sections and means for alternately connecting the series-multiple primary winding sections in series or parallel. The common primary winding section is in series with the series-multiple winding sections in both the series connection, wherein the higher primary voltage rating is $a+nb$, and in the parallel position wherein the lower primary voltage rating is $a+b$. None of the primary winding sections are tapped, and no winding end is open-ended and "floating" in either the series or parallel position.

BRIEF DESCRIPTION OF THE DRAWING

The above and further objects and advantages of the invention will be more readily apparent from the following detailed description when considered in conjunction with the accompanying drawing wherein:

FIGS. **1***a* and **1***b* schematically illustrate the series and the parallel connection respectively of the primary winding sections of a prior art dual voltage transformer having a non-integer series-parallel voltage ratio;

FIG. **2** schematically illustrates the high voltage surge and high voltage oscillations that can occur in the primary winding of a distribution transformer having a winding section with an open end when a surge occurs in the secondary winding, and

FIGS. **3***a* and **3***b* schematically illustrate the series and parallel connection respectively of the primary winding sections of a dual voltage rating transformer embodying the invention and having higher and lower primary voltage ratings which are not exact multiples of each other.

DETAILED DESCRIPTION

FIG. **1***a* schematically illustrates three primary winding sections **W1, W2,** and W3 of a prior art dual voltage distribution transformer having a non-integer series-parallel voltage ratio connected in series to provide the higher voltage rating, e.g., 19,920 volts. Winding sections **W1, W2** and W3 may be alternately connected in series or parallel by a suitable terminal board (not shown) or by a suitable series-multiple switch (not shown) such as the type disclosed in U.S. Pat. No. 3,170,048 to Charles E. Glatz et al. having the same assignee as this invention. The number of turns from the start **S1** of winding section **W1** to the finish **F1** thereof may be the same as the number of turns from the start **S2** of winding section **W2** to the finish **F2** thereof and also the same as the number of turns from start **S3** of winding section W3 to the finish **F3** thereof, and the voltage rating of each winding section **W1, W2** and W3 may be the same as they may be connected in parallel as illustrated in FIG. **1***b* to provide the lower primary voltage rating, e.g., 7620 volts, in the parallel position of the series-multiple switch or terminal board. The start **S1** of winding section **W1** may be connected to the primary bushing line terminal **H1** and the finish **F3** of winding section W3 may be grounded to the transformer tank or alternately connected to the primary bushing terminal **H2.** The higher primary voltage rating of 19,920 volts is not an integer (exact multiple) of the lower primary voltage rating of 7620 volts, and in order to accomplish the higher voltage rating a tap **T1** is pro-

vided at a point of winding section W3 where the voltage rating between start S3 and tap T1 is 2940 volts and the voltage rating between tap T1 and finish F3 is 4680 volts. In the series position, the series-multiple switch or terminal board may connect finish F1 of winding section W1 to start S2 of winding section W2 and also connect finish F2 of winding section W2 to tap T1 of winding section W3 so that the higher primary voltage rating in the series position is 7620 plus 7620 plus 4680 equals 19,920 volts.

However, in the series position shown in FIG. 1*a*, the start S3 of winding section W3 is open and floating. In a distribution transformer with a relatively high primary voltage, a high voltage surge and a series of high voltage oscillations may be generated in the primary winding when a surge exists in the secondary winding. FIG. 2 schematically illustrates that when a surge voltage such as V1 occurs in the secondary winding of a typical distribution transformer, a long duration oscillating voltage wave of higher magnitude such as V2 may exist in the primary winding (for example, between start S2 and open-ended start S3), and these high voltage oscillations decay only gradually. The magnitude of the primary oscillations may be considerably greater than the initiating surge, depending upon the voltage ratio and the circuit impedance. The generated surges and oscillations increase in magnitude with increase in surge impedance, and when the surge impedance approaches infinity, as in an open end winding, the magnitude of the generated surges and oscillations become particularly high. In one transformer tested the oscillation crest at the floating end of the open winding section was found to be approximately 230 percent of the initiating surge crest, and because oscillations are reflected and double instantaneous voltages, a 30 kilowatt secondary surge resulted in internal crest voltages in the order of 130 kilowatts in the open-ended winding sections and across the series multiple switch.

A similar surge reflection and voltage doubling occurs in the open winding section when the initiating voltage surge is applied to the primary winding.

In a transformer with a floating and open end winding such as start S3 of winding section W3, the surge and oscillations may be high enough when lighting currents enter the transformer through the secondary terminals to damage the primary winding and/or to flashover the series-multiple switch.

FIG. 3 illustrates dual rating distribution transformer embodying the invention having a non-integer series-parallel voltage ratio and wherein open and floating winding ends are eliminated in both the series and in the parallel position. The transformer primary winding may comprise three series-multiple primary winding sections *w*2, *w*3 and *w*4 of equal voltage ratings *b* (e.g., *b*=6150 volts) and a common primary winding section *w*1 having a voltage rating a (e.g., *a*=1470 volts) which rating is different than the voltage rating *b* of each of the series-multiple primary winding sections and which common winding section *w*1 is in series with the series-multiple winding sections *w*2, *w*3 and *w*4 in both the series position shown in FIG. 3*a* and in the parallel position shown in FIG. 3*b*.

The line bushing terminal H1 may be connected to the start S1 of common winding section *w*1, and the finish F4 of winding section *w*4 may be alternatively connected to the primary bushing terminal H2 or grounded to the tank. In the parallel position the starts S2, S3 and S4 of series-multiple winding sections *w*2, *w*3 and *w*4 may be commoned by a suitable terminal board (not shown) or by a series-multiple switch (not shown) and the finishes F2, F3 and F4 may also be commoned to connect the winding sections *w*1, *w*2 and *w*3 in parallel as shown in FIG. 3*b* and so that the their paralleled voltage rating is *b*=6150 volts, and the paralleled winding sections *w*2, *w*3 and *w*4 are connected in series with common primary winding section *w*1 whose voltage rating is *a*=1470 volts, so that the lower primary voltage rating is $a+b$, or 1470 plus 6150 equals 7620 volts.

In the series position shown in FIG. 3*a* the finish F2 of winding section *w*2 is connected to the start S3 of winding section *w*3 and the finish F3 thereof is connected to the start F4 of winding section *w*4 so that common section *w*1 is connected in series with series-multiple winding sections *w*2, *w*3 and *w*4 between bushing line terminal H1 and the terminal H2 or ground so that the higher primary voltage rating is $a+3b$, or 1470 plus three times 6150 equals 19920 volts. It will be noted that open winding ends are eliminated in both the series and in the parallel position. The higher primary voltage rating v_s for a transformer having a common primary winding section rated *a* and *n* series-multiple winding sections each rated *b* is $a+nb$ in the series position and the lower primary voltage rating v_p is $a+b$ in the parallel position. In summary:

$$a+nb=v_s \text{ (series)}$$

$a+b=v_p$ (parallel) Normally n is the smallest number of primary winding sections which results in a positive *a*. A negative *a* is, however, a valid solution and means that the common winding section *w*1 is reversed to that of the series-multiple winding sections *w*2, *w*3 and *w*4 so that the ampere turns of common winding section *w*1 subtract electrically from the ampere turns of winding sections *w*2, *w*3 and *w*4. For example, this would permit construction of a 2400 × 11,400 volt transformer with only three primary winding sections having no open ends and would thus theretically reduce the number of parallel winding sections.

The common winding section *w*1 carries a different magnitude of current and is of a different conductor size than the series-multiple winding sections *w*2, *w*3 and *w*4.

The disclosed winding arrangement is applicable (but not limited) to transformers having such non-integer series-parallel voltage ratings as 4800 × 13200 volts, 4800 × 13800 volts, 7200 × 19920 volts, 7620 × 19920 volts and 4160 × 13800 volts.

In the prior art arrangement illustrated in FIG. 1*a* each of the series-multiple primary winding sections W1, W2 and W3 must have graded "line end" insulation adjacent its start which is connected to the line bushing terminal H1, whereas in the disclosed invention graded line end insulation need only be provided in the common primary winding section *w*1 if the transformer is of the single bushing type with finish F4 of the winding section *w*4 grounded to the transformer tank.

Inasmuch as the common winding section *w*1 is always connected electrically in series with the series-multiple winding sections *w*2, *w*3 and *w*4 in both the series and parallel position, the transformer coil can be electrically balanced regardless of whether the common winding section portion and the series-multiple

winding section portions are arranged side-by-side or one over the other. Preferably the common primary winding section *w*1 extends the full axial length of the coil for best short circuit strength and the series-multiple primary winding sections *w*2, *w*3 and *w*4 are wound in concentric layers radially inward of, or outward from, the common winding section *w*1. Inasmuch as the common and the series-multiple winding sections are always electrically in series with each other in both the series and the parallel position, the transformer coil can be designed so that it is electrically balanced with consequent maximum short circuit strength.

It will be appreciated that in certain ratings of transformers having a non-integer series-multiple voltage ratio, the "common" and the "series-multiple" primary winding sections have the same voltage rating such as in a 4800 × 7200 volt transformer wherein the common primary winding section and the two series-multiple primary winding sections are all rated at 2400 volts.

It should be understood that I do not intend to be limited to the particular embodiment shown and described for many modifications and variations thereof will be readily apparent to those skilled in the art.

The embodiments of the invention in which an exclusive property or privilege is claimed are defined as follows:

1. A dual-voltage multi-winding transformer having a secondary winding and a primary winding comprising a plurality of untapped series-multiple primary winding sections of equal voltage rating and an untapped common primary winding section, and means for alternately connecting said series-multiple primary winding sections in series or parallel, said common primary winding section being in series with said series-multiple winding sections in both the series and the parallel connection thereof, the higher primary voltage rating of said transformer when said series-multiple primary winding sections are connected in series being a non-integer multiple of the lower primary voltage rating when said series-multiple winding sections are connected in parallel.

2. A dual-voltage transformer in accordance with claim **1** wherein said common winding section has a voltage rating different than that of said series-multiple primary winding sections.

3. A multi-winding series-multiple transformer having a non-integer series-parallel voltage ratio and a higher primary voltage rating of $a + nb$ and a lower primary voltage rating of $a + b$ comprising n untapped series-multiple primary winding sections each having a voltage rating of b and an untapped common primary winding section having a voltage rating of a which is different from b, where n is an integer, means for alternatively connecting said n series-multiple winding sections in series or in parallel, said common primary winding section being in electrical series relation with said series-multiple primary winding sections in both the series and the parallel connection thereof, and a secondary winding inductively linked with each of said primary winding sections.

4. A dual-voltage transformer in accordance with claim **1** wherein said higher primary voltage rating when said series-multiplier primary winding sections are connected in series is also a non-integer multiple of the voltage rating of said common winding section.

5. A dual-voltage tranformer in accordance with claim **2** wherein the ampere turns of said common winding section subtract electrically from the ampere turns of said series-multiple primary winding sections.

6. A dual-voltage tranformer in accordance with claim **1** wherein the only primary winding section provided with graded line-end insulation is said common winding section.

7. A dual-voltage transformer in accordance with claim **1** wherein said common primary winding section is wound in a cylindrical layer and said series-multiple primary winding sections are wound in respective cylindrical layers concentric with said common primary winding section layer.

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