

[54] **PHASE-ANGLE REGULATOR**
[72] Inventor: **Herbert L. Prescott**, Brookfield, Ohio
[73] Assignee: **Westinghouse Electric Corporation**, Pittsburgh, Pa.
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[58] Field of Search **323/43.5 R, 45, 120, 47, 114**

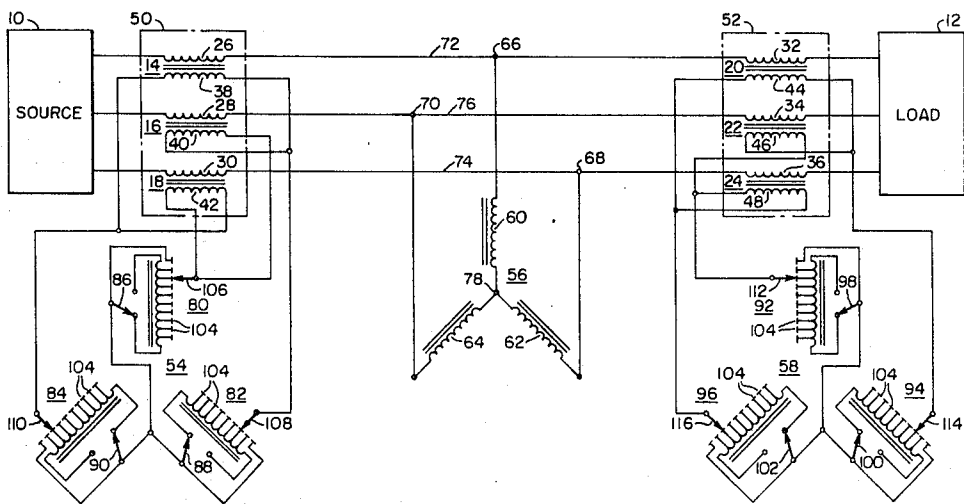
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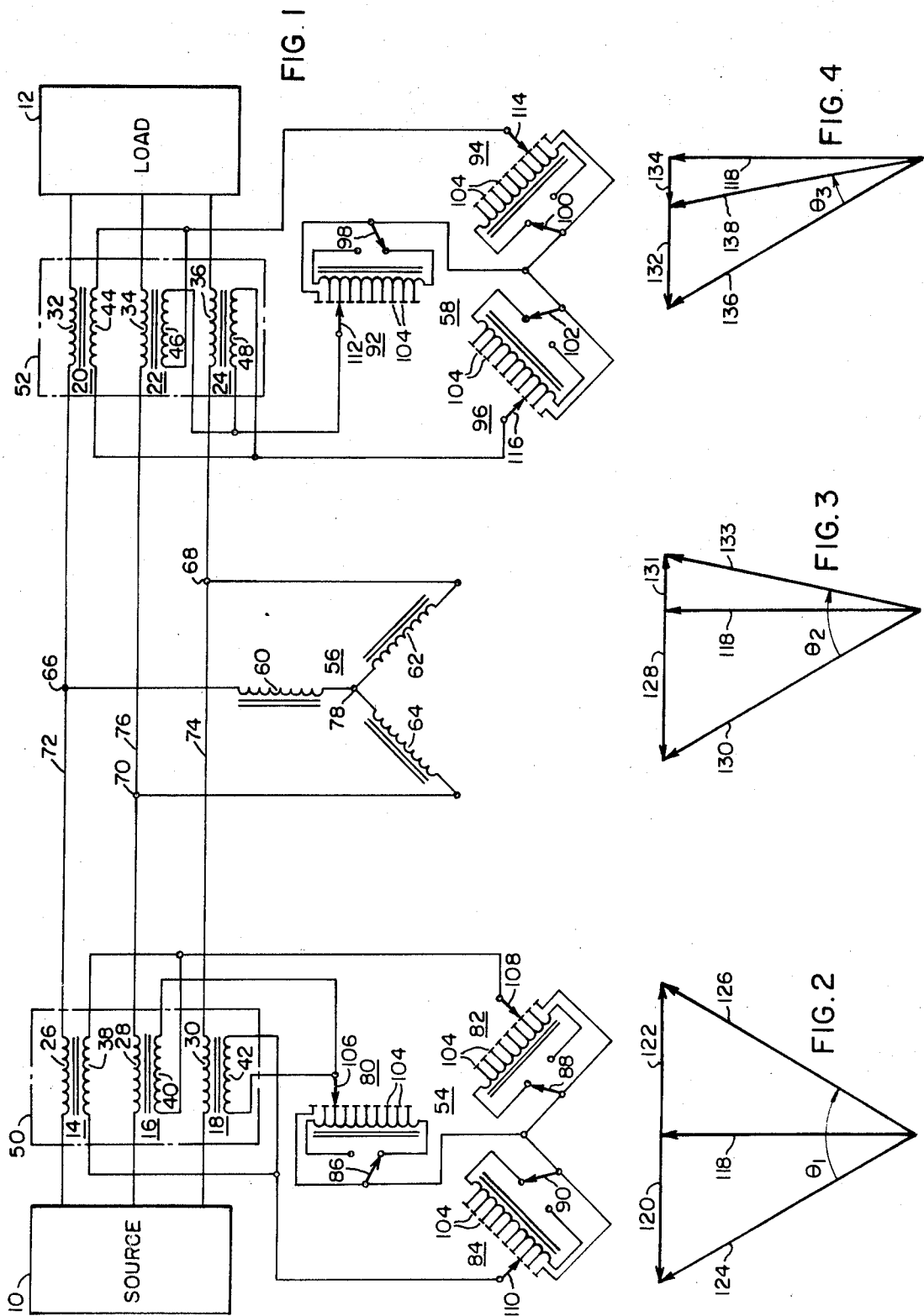
Primary Examiner—A. D. Pellinen
Attorney—A. T. Stratton and F. E. Browder

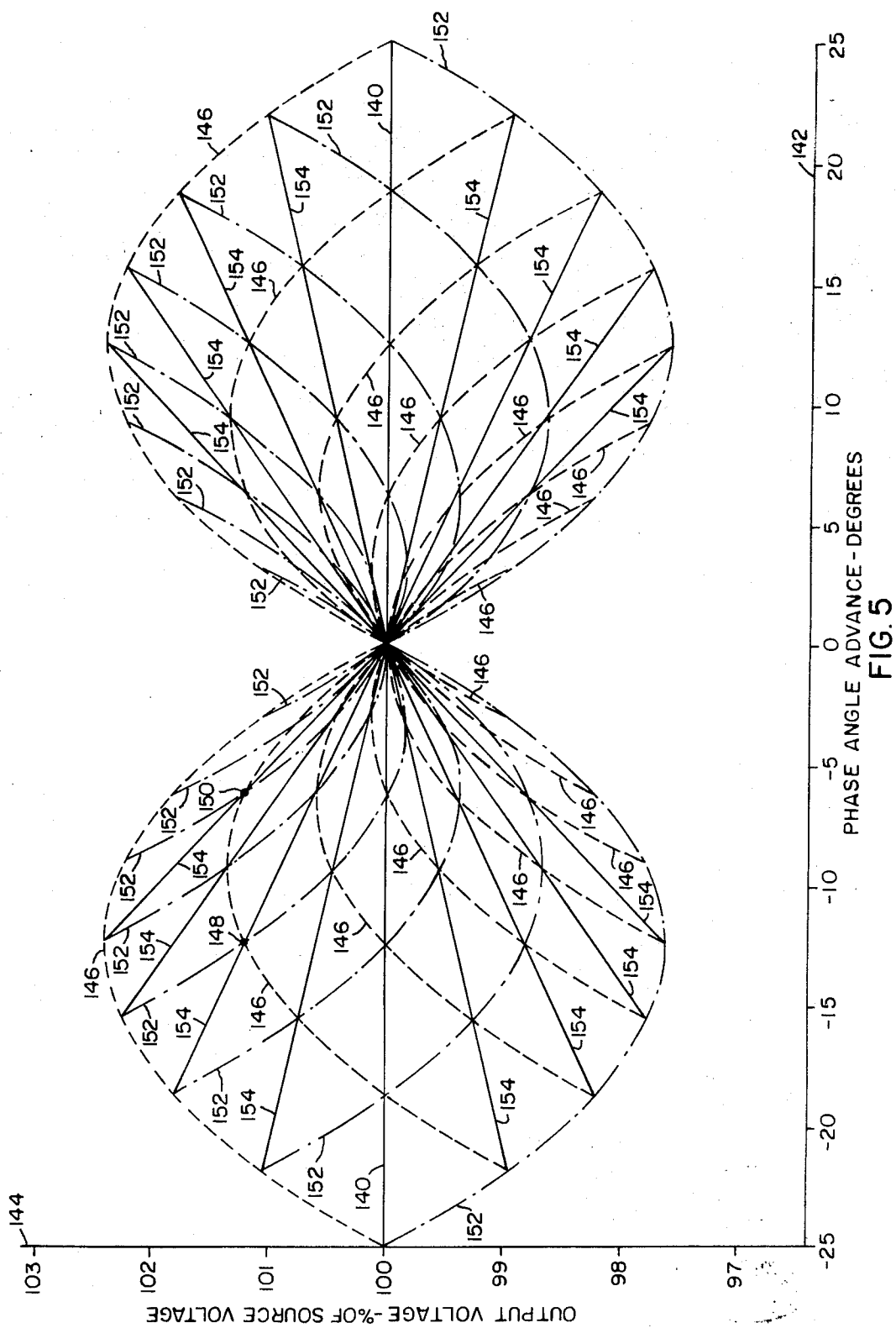
[57] **ABSTRACT**
Load tap changing regulator apparatus for high voltage power distribution systems. Two series transformers are used with separate excitation windings and tap changing means. The tap changers may be synchronized to provide phase-angle regulation with or without a change in the voltage.

[56] **References Cited**
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7 Claims, 5 Drawing Figures







PHASE-ANGLE REGULATOR

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates, in general, to electrical regulator apparatus and, more specifically, to tap changing phase-angle regulators.

2. Description of the Prior Art

Load tap changing regulator apparatus for high voltage power distribution systems must be capable of operating at the high voltages involved. The relatively large increases in power distribution voltage levels recently has made it necessary to redesign or rearrange load tap changing regulator apparatus to safely operate at the higher voltage. Although load tap changers have been designed for the higher voltages, conventional tap changing circuit arrangements impose limitations on the feasibility of tap changing high voltage power systems with available tap changers. Rearrangement of the load tap changers with their associated electrical inductive devices has been found necessary to provide a successful load tap changing regulator arrangement for high voltage systems.

One prior art load tap changing regulator arrangement uses two load tap changers which are effectively connected in series to provide the proper number of taps. With this arrangement, one of the tap changers operates at a relatively high potential above ground and therefore must be suitably constructed. Another prior art arrangement uses two load tap changers which are effectively connected in parallel. The current division in the two tap changers is dependent upon the balanced impedances in the excitation transformer, which may put serious limitations on the design of the system. In addition, damaging circulating currents can develop if the two tap changers are not synchronized properly.

These prior art load tap changing regulators provide phase-angle regulation without any significant voltage regulation. It is desirable in many applications to provide phase-angle regulation with some voltage regulation. Furthermore, it is desirable to provide a load tap changing regulator apparatus in which emergency operation could be maintained even if one load tap changer was not operating properly. Such a reliability and safety means is important in the design of electrical apparatus for the high voltage and heavily loaded systems now operating and proposed for the future.

SUMMARY OF THE INVENTION

The load tap changing regulator apparatus disclosed herein provides flexible operation while using load tap changers which have been used in the prior art arrangements. Each load tap changer is connected to a separate excitation winding and to a transformer which is placed serially between the source and the load. The load tap changers may be synchronized to provide phase-angle regulation only or phase-angle and voltage regulation. Since each load tap changer is not removed from ground potential by another load tap changer, the disclosed arrangement allows higher ratings than the prior art series arrangement. Circulating currents between load tap changers are not possible since the load tap changers are not directly interconnected. Furthermore, one tap changer may be operated independently to provide some degree of regulation if the other tap changer fails.

BRIEF DESCRIPTION OF THE DRAWINGS

Further advantages and uses of this invention will become more apparent when considered in view of the following detailed description and drawings, in which:

FIG. 1 is a schematic diagram of a load tap changing regulator constructed according to this invention;

FIGS. 2, 3 and 4 are phasor diagrams illustrating the relationship between the voltages of the regulator for different modes of operation; and

FIG. 5 is a graph illustrating the possible phase and voltage changes which may be provided by the regulator.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Throughout the following description, similar reference characters refer to similar elements in all figures of the drawing.

Referring now to the drawings, and FIG. 1 in particular, there is shown regulator apparatus for changing the phase and voltage relationship between the source 10 and the load 12. The source 10 may be any type of three-phase alternating current power source or delivery system and the load 12 may be any type power consuming or transferring system.

The series transformers 14, 16, 18, 20, 22 and 24 are serially connected between the source 10 and the load 12. The series transformers include secondary or line windings 26, 28, 30, 32, 34 and 36, and primary windings 38, 40, 42, 44, 46 and 48, respectively.

The series transformers may all be physically separate, that is, they may have separate magnetic core and housing structures. The series transformers 14, 16 and 18 may have a common magnetic core and housing structure to form the source-side series transformer 50. The series transformers 20, 22 and 24 may also have a common magnetic core and housing structure to form the load-side series transformer 52. In high power regulating systems, it is usually advantageous to have an assembly of smaller units rather than a few large units. This makes transportation easier and it reduces the repair costs of faulty units. Since conventional regulating circuits usually use a single series transformer having center tapped primary windings, the use of separate series transformers as taught by this invention is an advantage over conventional high power regulators.

The excitation windings 54, 56 and 58 may be the windings of a separate excitation transformer having a common magnetic structure or may be separate transformers which are properly interconnected to give the required phase relationships. Regardless of the physical relation between the excitation windings 54, 56 and 58, their respective phase windings are either in phase or 180° out of phase with each other. For purposes of discussion, the winding 56 will be considered as the primary winding of the excitation transformer and the windings 54 and 58 will be considered as tapped secondary windings of the excitation transformer.

The primary excitation winding 56 has one end of the phase windings 60, 62 and 64 connected to the terminals 66, 68 and 70 of the lines 72, 74 and 76, respectively. The other ends of each phase winding are connected to the terminal 78. Although illustrated in a wye-connection arrangement, this invention is equally applicable to a delta-connection arrangement.

The secondary excitation winding 54 has phase windings 80, 82 and 84 which are wye-connected. The phase reversing switches 86, 88, and 90 are used to increase the tap range. Similarly, the secondary excitation winding 58 has phase windings 92, 94 and 96 which are wye-connected with the phase reversing switches 98, 100 and 102 used to increase the tap range. The phase windings 80, 82, 84, 92, 94 and 96 are tapped by the contacts 104.

The source-side series transformer 50 has its primary windings connected, through the appropriate tap contacts, to the excitation phase windings so that a voltage is developed across the secondaries of the series transformer. The developed voltage is 90° out of phase with the respective line voltage. The load-side series transformer also has its primary windings connected through appropriate tap contacts to the excitation phase windings so that a voltage is developed across the secondaries of the series transformer 52. This voltage is also 90° out of phase with the respective line voltage. The movable contacts 106, 108 and 110 which are associated with the stationary contacts 104 connected to the winding 54, and the movable contacts 112, 114 and 116 which are associated with the stationary contacts 104 connected to the winding 58, are part of the tap changing mechanisms. They are shown in simple form to illustrate the invention. In practice, the movable contacts may include more than one contact assembly and may also include means to limit tap-to-tap currents during a tap change, such as a preventative autotransformer. The movable contacts 106, 108 and 110 of the excitation winding 54 may be mechanically interconnected so that the three-phase winding 54 may be balanced throughout the tap range. For a similar reason, the movable contacts 112, 114 and 116 may be mechanically interconnected. In certain modes of operation, all of the movable contacts may be mechanically interconnected.

The number of tap positions, the ratio of the winding turns and the rating of the windings are all dependent on the class and type of apparatus involved. Various combinations may be used without departing from the teachings of this invention. Although described in relation to a three-phase line system, it is readily apparent to one skilled in the art that the invention is applicable to a single-phase line system.

By synchronizing all of the movable contacts so that they tap equal portions of their respective phase windings, phase-angle regulation may be achieved without any change in the voltage. The voltage developed between the phase windings 82 and 84 is selected by the movable contacts 108 and 110 and applied to the primary winding 38 of the series transformer 14. This induces a voltage into the secondary winding 26 of the series transformer 14 and adds vectorially with the line voltage. The series transformers on both the source-side and load-side function similarly. The voltage components introduced by the series transformers are regulated in amplitude by the position of the movable contacts and in phase by the phase reversing switches. Changing the phase reversing switches causes the series transformer voltage component to reverse. That is, if the series transformer voltage component lagged the reference line voltage by 90° , changing the position of the phase reversing

switches would make the series transformer voltage component lead the reference line voltage by 90° .

A graphical representation of the vector addition of the voltages is shown in FIG. 2. The vector 118 represents the line voltage reference, the vector 120 represents the voltage on a source-side series transformer secondary, secondary, the vector 124 represents the voltage on a load side series transformer secondary, the vector 124 represents the resultant voltage of the vectors 118 and 120, and the vector 126 represents the resultant voltage of the vectors 118 and 122. This condition is achieved when all of the movable contacts are at similar positions on the phase windings and the phase reversing switches are positioned so that the source-side series transformer voltage component is 180° out of phase with the load-side series transformer voltage component. Since the vectors 124 and 126 are equal, a phase shift θ_1 is introduced without any voltage change.

FIG. 3 illustrates graphically the vector voltages existing when the movable contacts associated with the phases of the excitation winding 54 are not tapping contacts similar to the movable contacts associated with the excitation winding 58. The line voltage reference vector 118 adds vectorially with the source-side series transformer voltage vector 128 to produce the source-side voltage vector 130. The vector 131, representing the voltage of the load-side series transformer, has a smaller amplitude than the vector 128, thus the vector 133 which represents the load-side voltage has a different amplitude than the vector 130. Therefore, a phase shift θ_2 is provided by this arrangement with a difference in the source-side and load-side voltages.

In FIG. 4, the vector diagram illustrates a phase and voltage difference which is possible when the phase reversing switches are positioned so that the voltage components, which are represented by the series transformer vectors 132 and 134, have the same phase. The resulting source-side voltage 136 is greater than the load-side voltage 138. A phase shift θ_3 is also provided by this arrangement.

The voltage and phase differences possible with different tap locations and phase reversing switch positions is shown graphically in FIG. 5. The graph was drawn for a typical regulator arrangement having phase windings with 16 tap positions. The abscissa axis 140 is formed by a locus of points which indicate a phase change without a voltage change. The scale 142 gives the values of phase-angle change for the particular regulator apparatus used in drawing the graph. Points off of the abscissa indicate a change in both the phase and the voltage. The scale 144 gives the relative change between the source and the load voltages.

If losses are neglected, there is a particular position on the graph which represents the operation of the regulator for a specific position of the tapping contacts and phase reversing switches. That is, every combination of the tapping contacts and the phase reversing switches can be represented by its unique operating point on the graph. If the source-side and load-side series transformers are oppositely phased, and equal portions of the excitation phase windings are tapped, changing the tap positions in the same proportion will be indicated by a point along the line 140. The lines

146 indicate the locus of operating points established by varying the taps on the excitation winding 54 while the tap position on the excitation winding 58 does not change. The lines 146 have a spacing corresponding to four tap positions on the excitation winding 58, with the total number of tap positions being 32.

The phase reversing switches 98, 100 and 102 effectively give 32 tap operations with 16 tap positions. For example, with the winding 58 tapped at the 12th position, and with the phase reversal switches on the windings 54 and 58 set to provide series transformer voltage components which are 180° out of phase with each other, the point 148 represents the operating point when the excitation winding 54 is tapped in the fourth position. When the conditions stated above are the same except that the series transformer voltage components are in phase with each other, the point 150 represents the operating point. The lines 152 indicate the locus of points established by varying the taps on the winding 58 when the tap position on the winding 54 does not change. The solid lines 154 indicate the locus of points established by varying the taps on both windings 54 and 58 without varying the difference between the tap positions on both windings. That is, the taps are changed at the same rate after initially interlocking the tapping contacts at different positions.

Since numerous changes may be made in the above described apparatus and different embodiments of the invention may be made without departing from the spirit thereof, it is intended that all the matter contained in the foregoing description, or shown in the accompanying drawings, shall be interpreted as illustrative and not in a limiting sense.

I claim as my invention:

1. Regulator apparatus comprising first and second series transformers each having primary and secondary windings with first and second leads, the first lead of the secondary winding of said first series transformer being connected to the first lead of the secondary winding of said second series transformer, the second lead of the secondary winding of said first series transformer being adaptable for connection to a source of alternating-current potential, the second lead of the secondary winding of said second series transformer being adaptable for connection to a load, the primary winding of said first series transformer being connected to an excitation transformer winding which, when excited, induces a voltage into the secondary winding of said first series transformer which is 90° out of phase with the voltage existing between the first lead of the secondary winding of said first series transformer and another point, the primary winding of said second series transformer being connected to an excitation transformer winding which, when excited, induces a voltage into the secondary winding of said second series transformer which is 90° out of phase with the voltage existing between the first lead of the secondary winding of said second series transformer and said other point.

2. The regulator apparatus of claim 1 wherein the series transformers are connected to excitation transfor-

mers having tapped windings through tap changing means, said tap changing means selecting taps on the excitation windings which will induce the desired voltage in the series transformer secondary.

3. The regulator apparatus of claim 2 wherein the tap changing means selects taps which induce voltages into the series transformers which are equal in amplitude and are in phase with each other.

4. The regulator apparatus of claim 2 wherein the tap changing means selects taps which induce voltages into the series transformers which are equal in amplitude and are 180° out of phase with each other.

5. The regulator apparatus of claim 2 wherein the tap changing means selects taps which induce voltages into the series transformers which are in phase with each other and have unequal amplitudes.

6. The regulator apparatus of claim 2 wherein the tap changing means selects taps which induce voltages into the series transformers which are unequal in amplitude and 180° out of phase with each other.

7. Three-phase regulator apparatus comprising first and second series transformers each having three primary and three secondary windings with first and second leads, the first lead of a secondary winding of said first series transformer being connected to the first lead of a secondary winding of said second series transformers, the second lead of the secondary winding of said first series transformer being adaptable for connection to a three-phase alternating-current potential source, the second lead of the secondary winding of said second series transformer being adaptable for connection to a load, the primary windings of said first series transformer being connected through a first tap changing means to a first three-phase tapped excitation transformer winding which, when excited, induces a voltage into a secondary winding of said first series transformer which is 90° out of phase with the voltage existing between the first lead of said secondary winding of said first series transformer and another point, the primary windings of said second series transformer being connected through tap changing means to a second three-phase tapped excitation transformer winding which, when excited, induces a voltage into the secondary winding of said second series transformer which is 90° out of phase with the voltage existing between the first lead of said secondary winding of said second series transformer and another point, said tap changing means comprising movable and stationary contacts and phase reversing means which determine the magnitude and phase of the induced voltages in the secondaries of said series transformers, said tap changing means providing, when the phase reversing switches are in one position, induced voltages in the secondaries of said first series transformer which are 180° out of phase with the induced voltages in the secondaries of said second series transformer, and when the phase reversal switches are in another position, induced voltages in the secondaries of said first series transformer which are in phase with the induced voltages in the secondaries of said second series transformer.

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