Nov. 5, 1957 B. G. WRIGHT 2,812,488

VOLTAGE REGULATING TRANSFORMER SYSTEM WITH PERMANENT PHASE SHIFT

Filed July 11, 1955 5 Sheets-Sheet 1

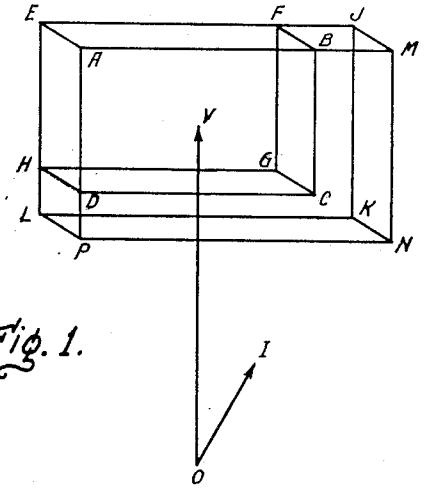


Fig. 1.

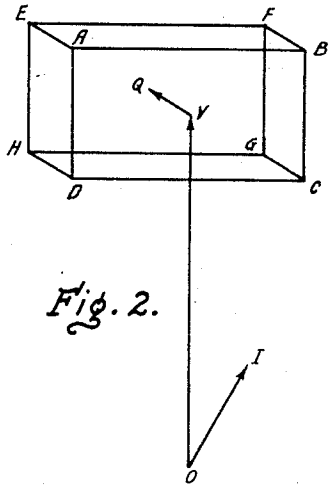


Fig. 2.

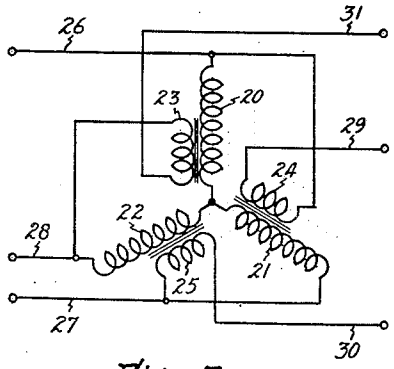


Fig. 3.

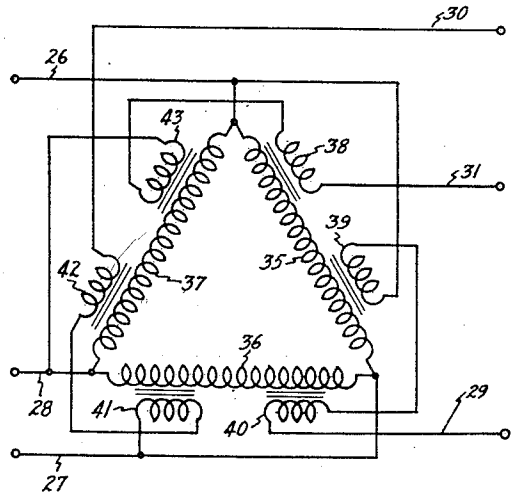


Fig. 4.

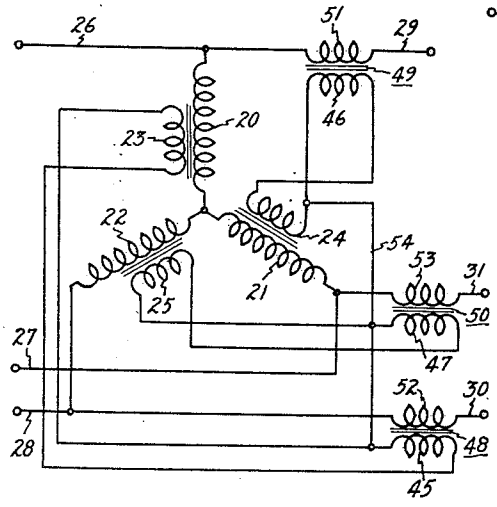


Fig. 5.

Inventor
Burton G. Wright,
by Gilbert C. Tarleton
His Attorney.

Nov. 5, 1957 B. G. WRIGHT 2,812,488

VOLTAGE REGULATING TRANSFORMER SYSTEM WITH PERMANENT PHASE SHIFT

Filed July 11, 1955 5 Sheets-Sheet 2

Fig. 6.

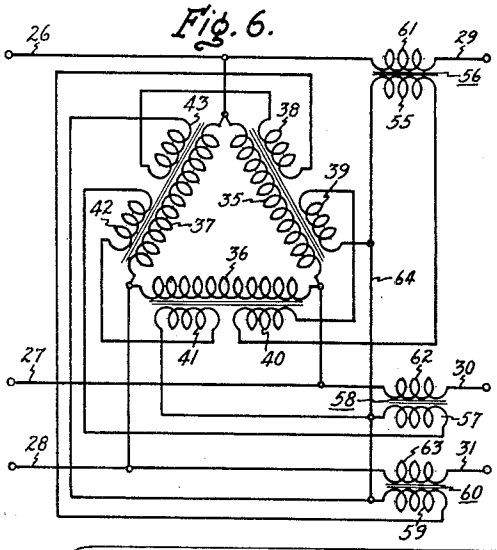


Fig. 7.

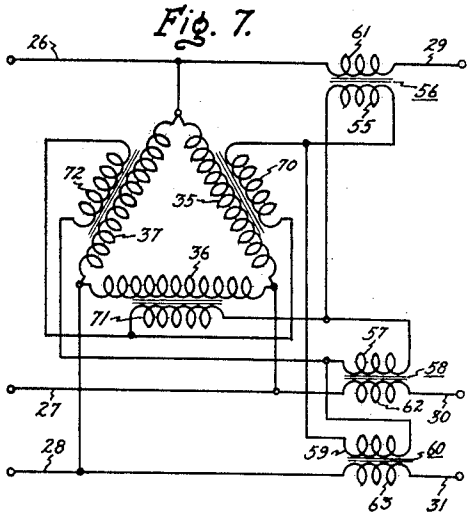


Fig. 8.

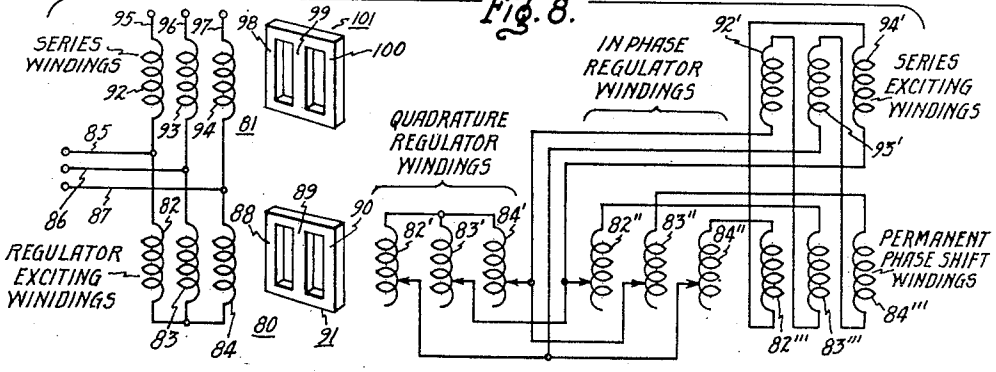
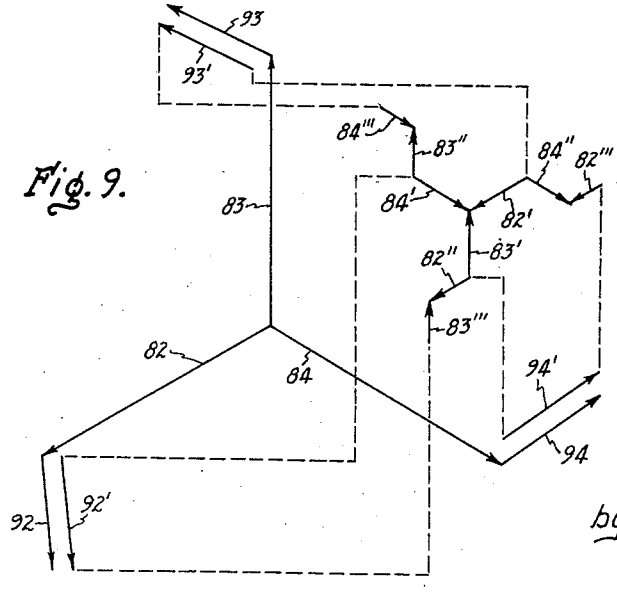


Fig. 9.



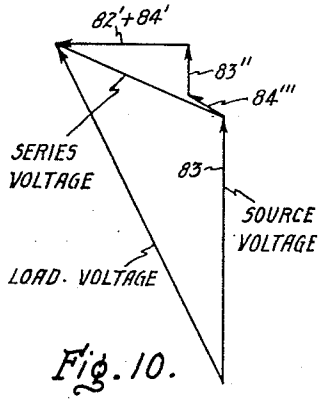


Fig. 10.

Inventor
Burton G. Wright,
by Gilbert C. Tarleton
His Attorney.

Nov. 5, 1957 B. G. WRIGHT 2,812,488

VOLTAGE REGULATING TRANSFORMER SYSTEM WITH PERMANENT PHASE SHIFT

Filed July 11, 1955 5 Sheets-Sheet 3

Fig. 11.

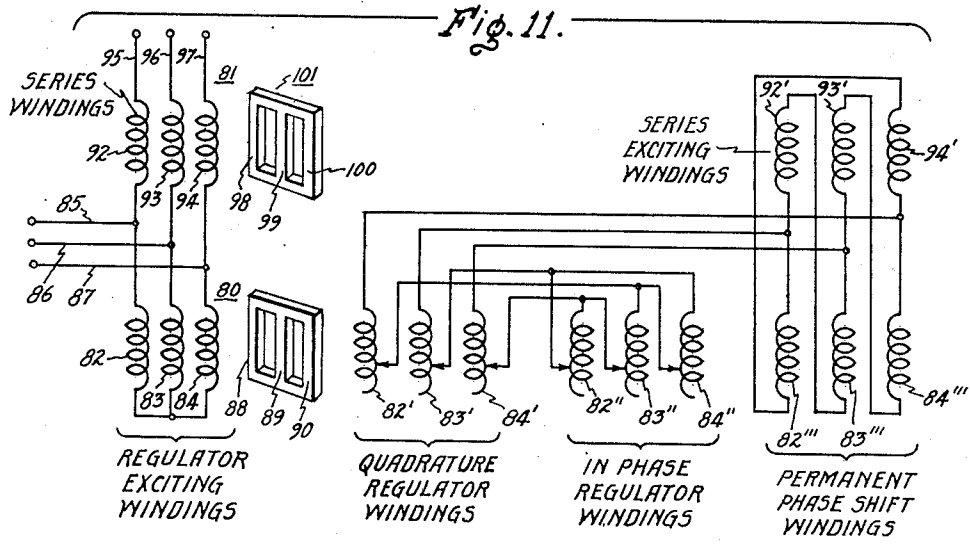


Fig. 12.

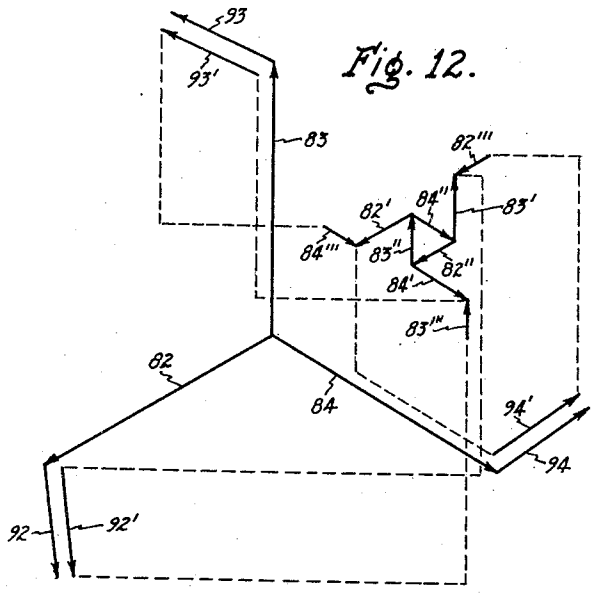
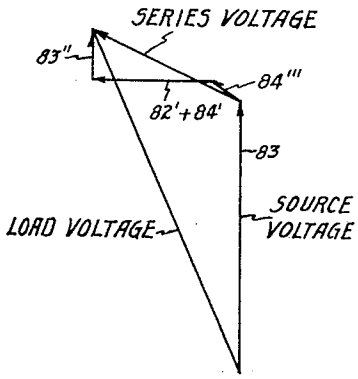


Fig. 13.



Inventor
Burton G. Wright,
by Gilbert P. Tarleton
His Attorney.

Nov. 5, 1957 B. G. WRIGHT 2,812,488

VOLTAGE REGULATING TRANSFORMER SYSTEM WITH PERMANENT PHASE SHIFT

Filed July 11, 1955 5 Sheets-Sheet 4

Fig. 14.

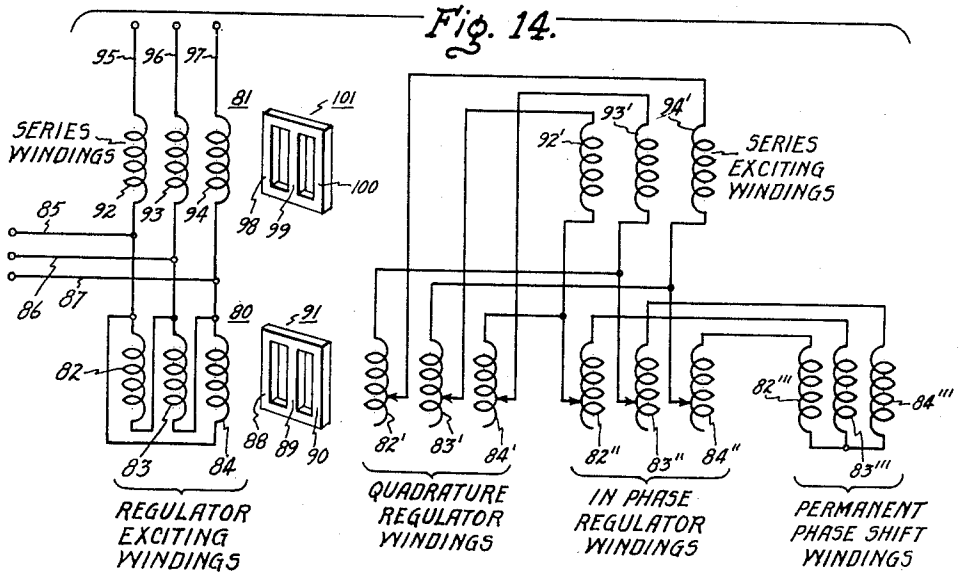


Fig. 15.

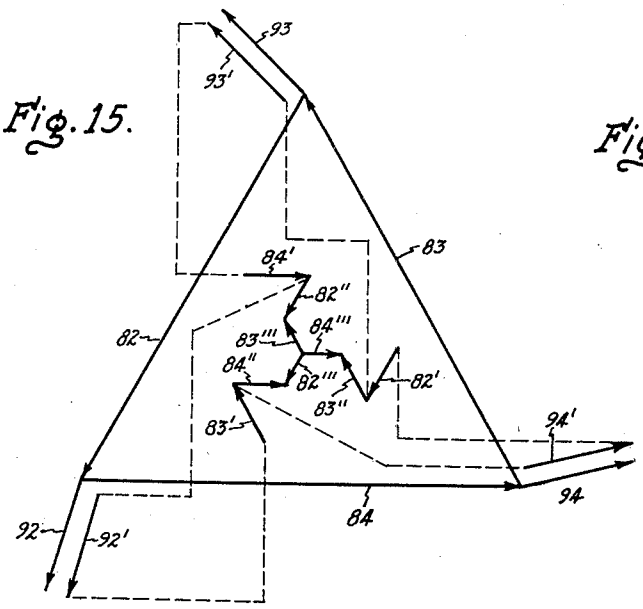
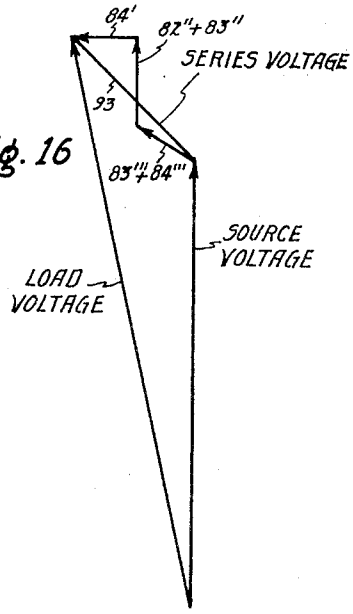


Fig. 16



Inventor
Burton G. Wright,
by Gilbert P. Tarleton
His Attorney.

Nov. 5, 1957 B. G. WRIGHT 2,812,488

VOLTAGE REGULATING TRANSFORMER SYSTEM WITH PERMANENT PHASE SHIFT

Filed July 11, 1955 5 Sheets-Sheet 5

Fig. 17.

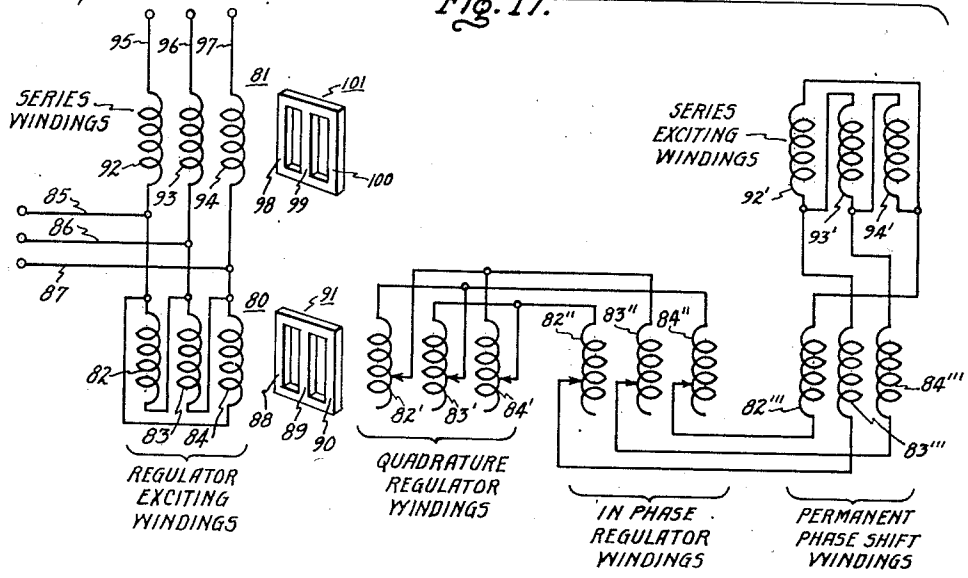


Fig. 18.

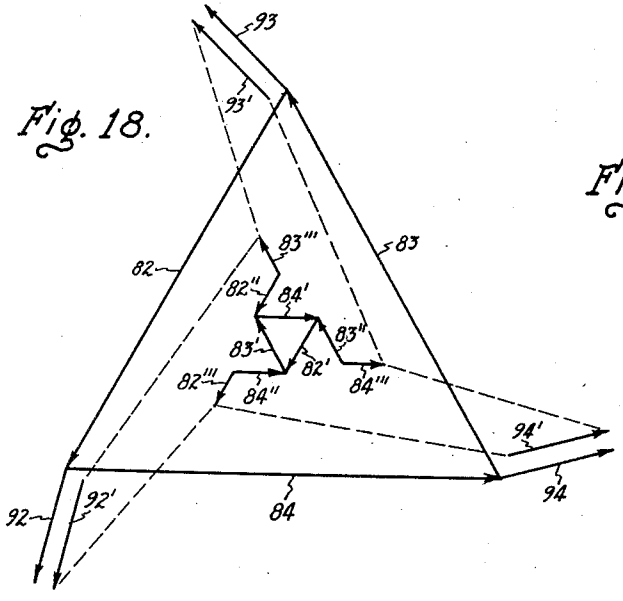
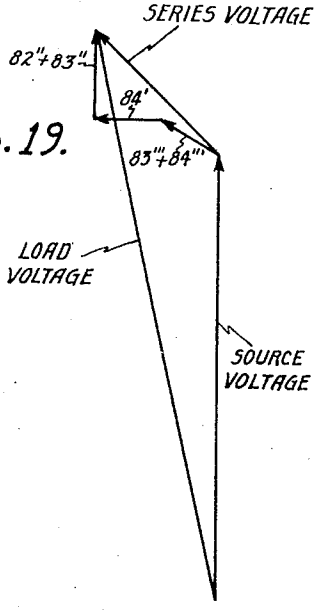


Fig. 19.



Inventor
Burton G. Wright,
by Gilbert P. Tarleton
His Attorney.

United States Patent Office 2,812,488
Patented Nov. 5, 1957

2,812,488

VOLTAGE REGULATING TRANSFORMER SYSTEM WITH PERMANENT PHASE SHIFT

Burton G. Wright, Lanesborough, Mass., assignor to General Electric Company, a corporation of New York

Application July 11, 1955, Serial No. 521,240

13 Claims. (Cl. 323—47)

This invention relates to voltage regulating transformer systems, and more in particular to an improved means for compensating for internal impedance voltage drop in a series voltage regulating transformer system.

Voltage regulating transformer systems circuits of the type wherein the magnitude and relative phase angle of the voltage of an alternating current power source may be varied have been commonly employed to reduce circulating currents when a plurality of such alternating current power sources are connected for parallel operation. In a typical system of this type, a secondary winding of a transformer is connected in series with each output lead of the power source, and the primary windings of the series transformers are energized by in-phase and quadrature voltages. The phase angle and magnitude of the voltage output of the alternating current power source may be varied over a limited range. This type of voltage regulating system is disclosed in U. S. Patent No. 2,196,029 which issued April 2, 1940, on an application of Z. O. St. Palley and is assigned to the present assignee.

It has been found in such systems however, that the range of variation of magnitude and phase angles of the output voltage for which the voltage regulator is designed is reduced due to the internal impedance voltage drop of the regulator. In order to compensate for this, it has been common to increase the range of regulation obtainable by the regulator. This necessarily results in increase in size, weight and cost of the regulator, and as will be shown more clearly in the following disclosure, also results in a portion of the range serving no useful purpose.

It is therefore an object of this invention to provide a voltage regulating transformer system having improved means for compensating for the effect of internal impedance voltage drops in the transformer.

It is also an object to provide a new and improved voltage phase angle and voltage magnitude regulating transformer system wherein the effect of internal regulation of the transformer system due to internal impedance voltage drop therein is compensated for by means providing a voltage having a permanent phase shift.

Briefly stated, in accordance with one aspect of my invention, I take advantage of the fact that most power circuit loads have a power factor of about 0.85, and that as a result the load current through the series regulating transformer has a phase angle of about 30° with respect to the voltage. The internal impedance of the regulating transformer consists principally of inductive reactance, and therefore the internal impedance voltage drop of the series transformer has a phase angle of about 90° with respect to the current, and the internal impedance voltage drop has a phase angle of about 60° with respect to the induced voltage of the secondary winding of the transformer. In my invention then, the internal regulation of the transformer is compensated for by an induced voltage in the series regulator winding that has a phase angle of approximately 60° to the voltage of the alternating current power source, and has a magnitude substantially equal to the internal impedance drop for a predetermined load. In a three phase system this 60° phase angle voltage may be readily obtained for each phase from the voltage of the other phases. Means are also employed to provide a voltage which is variable in both magnitude and phase with respect to the source voltage, or separate variable quadrature and in-phase voltages in the series winding in order to vary the phase and magnitude of the output voltage of the voltage regulator. The use of the compensating or permanent phase shift voltage permits the use of smaller tapped secondary windings and smaller associated tap changing equipment to obtain the desired phase and magnitude regulation.

My invention will be better understood from the following description taken in connection with the accompanying drawings.

In the drawings:

Fig. 1 is a vector and regulation diagram of one phase of a previously used voltage regulating transformer system,

Fig. 2 is a vector and regulation diagram of one phase of the voltage regulating transformer system of my invention,

Figs. 3 and 4 are circuit diagrams for simplified direct voltage regulation transformer systems useful in my invention, Fig. 3 illustrating a Y-connected system and Fig. 4 illustrating a delta-connected system,

Figs. 5, 6 and 7 are circuit diagrams for simplified indirect voltage regulation transformer systems useful in my invention, Fig. 5 illustrating a Y-connected system, Fig. 6 illustrating one modification of a delta-connected system, and Fig. 7 illustrating another modification of a delta-connected system,

Fig. 8 is a more complete circuit diagram of one embodiment of my invention,

Fig. 9 is a vector diagram of the circuit of Fig. 8,

Fig. 10 is a vector diagram of a single phase of the circuit of Fig. 8,

Fig. 11 is a more complete circuit diagram of another embodiment of my invention,

Fig. 12 is a vector diagram of the circuit of Fig. 11,

Fig. 13 is a vector diagram of a single phase of the circuit of Fig. 11,

Fig. 14 is a more complete circuit diagram of still another embodiment of my invention,

Fig. 15 is a vector diagram of the circuit of Fig. 14,

Fig. 16 is a vector diagram of a single phase of the circuit of Fig. 14,

Fig. 17 is a more complete circuit diagram of still another embodiment of my invention,

Fig. 18 is a vector diagram of the circuit of Fig. 17, and

Fig. 19 is a vector diagram of a single phase of the circuit of Fig. 17.

Referring now to the drawings, and more in particular to Fig. 1, the vector OV therein illustrated represents the exciting winding or input voltage of a voltage regulation transformer system, and the vector OI represents the load current which flows through the series regulating winding. The rectangle ABCD represents the phase and magnitude regulation under load which is desired. This regulation is accomplished by the addition of in-phase and quadrature voltages to the voltage OV, or by the addition of a voltage that is variable in magnitude and phase with respect to the voltage OV. The resultant voltage regulator output voltage, which may be drawn from the point O to any point within the rectangle ABCD, has been omitted from the drawing for the sake of clarity. In order to obtain the regulation range represented by rectangle ABCD, however, it is necessary to design the regulator to cover the range defined by rectangle EFGH due to the internal regulation effect

provided by the internal regulator impedance. The internal impedance is represented by the lines EA, FB, GC, and HD. Since it is common in this type of regulator to employ the same tapped transformer secondary winding for obtaining both positive and negative values of voltage for regulation, the winding connections being reversed for opposite polarities, the winding must be designed to provide the maximum voltage that is required. Thus in Fig. 1, the tapped secondary winding for varying the magnitude of the output voltage must be designed to provide a maximum positive voltage equal to the distance from the end of the vector OV to the line EF, similarly, the tapped secondary winding for varying the phase angle of the output voltage must be designed to provide a maximum voltage equal to the distance from the end of vector OV to the line HE. This results in the necessity for designing the secondary windings for phase and magnitude regulation to obtain a regulation range represented by the rectangle EJKL, and the resultant output voltage regulation is represented by the rectangle AMNP, the lines JM, KN and LP representing the internal impedance voltage drop in the regulator. Since the desired range of regulation lies within the rectangle ABCD, the remaining area BMNPDC represents a range of obtainable regulation that is of no useful purpose.

According to my invention, however, as illustrated in the vector and regulation diagram of Fig. 2, the voltage regulator is designed to obtain the desired phase and magnitude regulation as represented by the rectangle ABCD, and a voltage represented by the vector VQ is added to the primary voltage OV. The voltage VQ is substantially equal in magnitude and opposite in polarity to the internal impedance voltage drop of the voltage regulator at a predetermined load as represented by lines EA, FB, GC, and HD. Since, as previously stated, the normal power factor of most power circuit loads is about 0.85, the load current OI through the regulator lags the exciting voltage OV by about 30°. The internal impedance voltage drop of the voltage regulator has a phase angle of about 90° with respect to the current OI, and therefore has a phase angle of about 60° with respect to the exciting voltage OV. Therefore, in most applications of the voltage regulator, the compensating or permanent phase shift voltage VQ should have a phase angle of about 60° with respect to the exciting voltage OV.

Two direct methods for obtaining the permanent phase shift voltages are illustrated in Figs. 3 and 4. For the sake of clarity, the transformer secondary windings for obtaining in-phase and quadrature voltages have been omitted from these circuit diagrams.

Referring now to Fig. 3, a three phase Y-connected regulator of three single phase Y-connected regulators are therein illustrated having three exciting windings **20**, **21**, **22** and three secondary windings **23**, **24** and **25** respectively. The three exciting windings are connected by way of power supply lines **26**, **27** and **28** respectively to a three phase source of power (not shown). The power supply lines **26**, **27**, and **28** are connected in series with secondary windings **24**, **25** and **23** respectively to a three phase load (not shown) by way of power lines **29**, **30** and **31** respectively, so that a voltage is induced in the series winding of each phase of the power circuit that has a 60° leading phase angle with respect to the voltage of each phase. For example, the voltage induced in secondary winding **24** which is in series with power supply lead **26** has a phase angle of 60° leading with respect to the voltage of the exciting winding **20** which is connected to the power supply lead **26**. The voltage induced in the secondary winding **24** corresponds to the voltage represented by the vector VQ of Fig. 2.

In the circuit illustrated in Fig. 4, a three phase voltage regulator, or three single phase voltage regulators, has three exciting windings **35**, **36** and **37** delta-connected to the power supply lines **26**, **27** and **28**, and each exciting winding has a pair of secondary windings inductively coupled thereto. Secondary windings **33** and **39** are inductively coupled to exciting winding **35**, secondary windings **40** and **41** are inductively coupled to exciting winding **36**, and secondary windings **42** and **43** are inductively coupled to exciting winding **37**. Each of the power supply lines **26**, **27** and **28** are connected in series with two secondary windings so that the resultant voltage of the two respective seconadry windings has a phase angle of 60° with respect to the phase of the voltage on the respective power supply lead (with all secondary windings being identical). Thus power supply line **26** is connected in series with secondary windings **39** and **40**, power supply line **27** is connected in series with secondary windings **41** and **42**, and power supply line **28** is connected in series with secondary windings **43** and **38**. The modification of Fig. 4 has greater flexibility than that of Fig. 3, since the relative sizes of the two secondary windings in series with each phase may be varied to obtain angular phase displacements of the resultant voltage between the limits of 30° and 90°.

In Figs. 5, 6 and 7 are illustrated three simplified circuits for the indirect method of voltage regulation, wherein the voltages of each phase are regulated by separate series connected transformers.

The circuit shown in Fig. 5 is similar to the circuit of Fig. 3, with the exception that the secondary windings **23**, **24** and **25** are connected to the exciting windings **45**, **46** and **47** respectively of series transformers **48**, **49** and **50** respectively, and the power supply lines **26**, **27** and **28** instead of being connected in series with the secondary windings of the voltage regulator as in Fig. 3, are connected in series with the secondary windings **51**, **53** and **52** respectively of series transformers **49**, **50** and **48** respectively. The neutral ends of the secondary windings **23**, **24** and **25** are each connected to a neutral bus **54**. The series transformers **48**, **49** and **50** may be separate single phase transformers, or they may comprise a three phase transformer.

The circuit shown in Fig. 6 is similar to the circuit of Fig. 4 with the exception that the secondary windings **39** and **40** are connected to the exciting winding **55** of series transformer **56**, secondary windings **41** and **42** are connected to exciting winding **57** of series transformer **58**, and secondary windings **43** and **38** are connected to exciting winding **59** of series transformer **60**. The power supply lines **26**, **27** and **28** instead of being connected in series with the secondary windings of the regulator transformer as in Fig. 4, are connected in series with the secondary windings **61**, **62** and **63** of series transformers **56**, **58** and **60** respectively. One end of each of the exciting windings **55**, **57** and **59** is connected to a neutral bus **64**. The series transformers **56**, **58** and **60** may be separate single phase transformers, or they may comprise a three phase transformer.

The circuit of Fig. 7 is a modification of the circuit of Fig. 6 in which each phase of the regulator transformer has only one secondary winding. In this circuit the secondary windings **70**, **71** and **72** inductively coupled to the regulator transformer exciting windings **35**, **36** and **37** respectively are Y-connected and an exciting winding of the series transformers **55**, **57** and **59** is connected across each pair of secondary windings of the regulator transformer. Thus the secondary windings **70** and **71** are connected to exciting winding **55** of series transformer **56**, secondary windings **71** and **72** are connected to exciting winding **57** of series transformer **58**, and secondary windings **70** and **72** are connected to exciting winding **59** of series transformer **60**. This circuit arrangement has the advantage that only one secondary winding is required for each phase of the regulator transformer, and also that the exciting windings of the series transformers are connected in delta arrangement. The delta connection provides a circulating path for reflected zero phase se-

quence currents whose originals may flow in the main power circuit. This largely eliminates such zero phase sequence currents from flowing in the secondary windings of the regulator transformer. The delta connection also provides a circulating path for core magneitzing harmonic currents, thus largely eliminating such harmonic voltages of that particular core from the main power circuit.

Figs. 8–19 illustrate the circuit and vector diagrams of four embodiments of my invention wherein the basic circuits previously described are incorporated in regulator transformer circuits having in-phase and and quadrature regulation.

Referring now to Fig. 8, therein is shown a three phase regulator transformer 80 and a three phase series transformer **81**. The regulator transformer **80** has three exciting windings 82, 83 and 84 Y-connected to three phase power lines **85**, **86** and **87**, the exciting windings **82**, **83** and 84 being wound on the legs **88**, **89** and **90** respectively of the three phase core **91**. The series transformer **81** has secondary windings **92**, **93** and **94** connected in series between the three phase power lines **85**, **86** and **87** and three phase feeders lines **95**, **96** and **97** respectively. The secondary windings **92**, **93** and **94** are wound on the legs **98**, **99** and 100 respectively of series transformer core **101**.

The regulator transformer **80** has three tapped quadrature secondary windings **82'**, **83'** and **84'**, three tapped in-phase secondary windings **82''**, **83''** and **84''**, and three permanent phase shift windings **82'''**, **83'''**, and **84'''** inductively coupled to the exciting windings **82**, **83** and **84** respectively. The secondary windings **92**, **93** and **94** of series transformer **81** are inductively coupled to three exciting windings **92'**, **93'** and **94'** respectively.

The quadrature windings **82'**, **83'** and **84'** are Y-connected on one end, and the other end of the quadrature windings are connected to one end of the in-phase windings **84''**, **82''** and **83''** respectively, and the other ends of the in-phase windings in the above order are connected to one end of the permanent phase shift windings **82'''**, **83'''** and **84'''** respectively.

The exciting winding **92'** of the series transformer **81** has one end connected to the other end of permanent phase shift winding **83'''** and the other end connected to the junction between quadrature winding **84'** and in-phase winding **83''**. The exciting winding **93'** of series transformer **81** has one end connected to the other end of permanent phase shift winding **84'''**, and the other end connected to the junction between quadrature winding **82'** and in-phase winding **84''**. The exciting winding **94'** has one end connected to the other end of permanent phase shift winding **82'''** and the other end connected to the junction between quadrature winding **83'** and in-phase winding **82''**.

The relative phase angles of the voltages of the circuit of Fig. 8 may be more clearly seen in the overall vector diagram of Fig. 9 and the single phase vector diagram of Fig. 10. From these diagrams it may be seen that for each phase the quadrature voltage is obtained from the sum of the voltages of two quadrature windings and the in-phase voltage is obtained from an in-phase winding.

In the circuit of Fig. 11, the regulator exciting windings **82**, **83** and **84**, and the series windings **92**, **93** and **94** are connected the same as in Fig. 8. In this circuit, however, the in-phase secondary windings **82''**, **83''** and **84''** are delta-connected, and one end of each quadrature winding is connected to the junction of the in-phase windings of the respective opposite phases. The other end of the quadrature windings **82'**, **83'** and **84'** are connected to one end of the permanent phase shift windings **84'''**, **82'''** and **83'''** respectively. The series exciting winding **92'** has one end connected to the other end of permanent phase shift winding **83'''**, and the other end connected to the junction between quadrature winding **83'** and permanent phase shift winding **82'''**. The series exciting winding **93'** has one end connected to the other end of permanent phase shift winding **84'''** and the other end connected to the junction between quadrature winding **84'** and permanent phase shift winding **83'''**. The series exciting winding **94'** has one end connected to the other end of permanent phase shift winding **82'''**, and the other end connected to the junction between quadrature winding **82'** and permanent phase shift winding **84'''**. The phase relationships for this circuit may be more readily seen in the overall vector diagram of Fig. 12 and the phase vector diagram of Fig. 13.

In the circuit illustrated in Fig. 14, the regulator exciting windings are delta-connected to the power source lines **85**, **86** and **87** and the permanent phase shift windings **82'''**, **83'''** and **84'''** are Y-connected. The end of the permanent phase shift winding **82'''** is connected to one end of the in-phase winding **84''** which is in turn connected to one end of quadrature winding **83'**. The end of the permanent phase shift winding **83'''** is connected to one end of the in-phase winding **82''** which is in turn connected to one end of quadrature winding **84'**. The end of the permanent phase shift winding **84'''** is connected to one end of the in-phase winding **83''** which is in turn connected to one end of quadrature winding **82'**. The series exciting winding **92'** is connected between the other end of quadrature winding **83'** and the junction between quadrature winding **84'** and in-phase winding **82''**. The series exciting winding **93'** is connected between the other end of quadrature winding **84'** and the junction of quadrature winding **82'** and in-phase winding **83''**. The series exciting winding **94'** is connected between the other end of quadrature winding **82'** and the junction of quadrature winding **83'** and in-phase winding **84''**. The phase relationships of the windings may be more clearly seen in the overall vector diagram of Fig. 15 and the phase vector diagram of Fig. 16.

In the circuit illustrated in Fig. 17, the regulator exciting windings **82**, **83** and **84** and the series windings **92**, **93** and **94** are connected the same as in the circuit of Fig. 14. In this circuit, however, the quadrature regulator windings **82'**, **83'** and **84'** are delta-connected, and the series exciting windings **92'**, **93'** and **94'** are also delta-connected. The series combination of permanent phase shift winding **83'''** and in-phase winding **82''** is connected between the junctions of quadrature windings **83'** and **84'** and series exciting windings **92'** and **93'**. The series combination of permanent phase shift winding **84'''** and in-phase winding **83''** is connected between the junctions of quadrature windings **82'** and **84'** and series exciting windings **93'** and **94'**. The series combination of permanent phase shift winding **82'''** and in-phase winding **84''** is connected between the junctions of quadrature windings **82'** and **83'** and series exciting windings **92'** and **94'**. The phase relationships of the windings of this circuit may be more clearly seen from the vector diagrams of Figs. 18 and 19.

In each of the previously disclosed circuits a voltage having a permanent phase shift with respect to the source voltage has been added to the series winding of the regulator. This voltage is approximately equal in magnitude to the voltage drop in the regulator due to internal impedance at a predetermined load and has such a phase angle that the effect of the internal impedance voltage drop is substantially cancelled. While various means may be employed to obtain a voltage of the correct phase angle to serve this purpose, it has been found that in most applications a voltage having a phase angle of 60° with respect to the source voltage is easily obtainable and has approximately the correct phase angle. This results from the fact that the majority of load circuits have power factors of about 0.85. Although the previously disclosed circuits employ in phase and quadrature regulation voltages, it is obvious that a voltage having variable magnitude and phase with respect to the source voltage may also be employed and a circuit providing such a voltage is the equivalent of the circuits disclosed.

It will be understood, of course, that, while the forms

of the invention herein shown and described constitute preferred embodiments of my invention, it is not intended herein to illustrate all of the possible equivalent forms or ramifications thereof. 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, and it is aimed in the appended claims to cover all such changes as fall within the true spirit and scope of my invention.

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

1. A voltage regulating transformer system comprising exciting transformer means, series winding means coupled to said exciting transformer means, a source of potential connected to said exciting transformer means and one end of said series winding means, the other end of said series winding means being connected to a load circuit, means inducing a voltage variable in magnitude and phase with respect to said source potential in said series winding means, and means for inducing a voltage in said series winding means that is substantially equal in magnitude to the internal impedance voltage drop of said series winding means for a predetermined load and having a phase angle of about 60° leading with respect to the voltage of said source of potential.

2. A voltage regulating transformer system for a polyphase circuit comprising exciting transformer means connected to a source of polyphase voltage, series winding means for each phase of said polyphase source connected in series between said polyphase source of voltage and a load circuit, means inducing a voltage variable in magnitude and phase with respect to said source voltage in each of said respective series winding means for each of said phases, and means inducing a voltage in each of said series winding means substantially equal in magnitude and opposite in phase to the internal impedance voltage drop of said series winding means for a predetermined load.

3. A voltage regulating transformer system for a polyphase circuit comprising exciting transformer means connected to a source of polyphase voltage, series winding means for each phase of said polyphase source connected in series between said polyphase source of voltage and a load circuit, means inducing a voltage variable in magnitude and phase with respect to said source voltage in each of said respective series winding means for each of said phases, and means inducing a voltage in each of said series winding means substantially equal in magnitude to the internal impedance voltage drop of said series winding means for a predetermined load and having a phase angle of about 60° leading the voltage of the respective phase of said source of voltage.

4. In a voltage regulating transformer system for three phase circuits of the type having exciting transformer windings either detla or Y-connected to a source of three phase voltage and a series transformer winding connected in each phase between said source of three phase voltage and a load circuit, means for inducing variable in-phase and quadrature voltage in each of said series windings, and means inducing a permanent phase shift voltage in each of said series windings substantially equal in magnitude to the internal impedance voltage drop of the respective series windings for a predetermined load and having a phase angle of 60° leading the voltage of the respective phase of said source of voltage, said in-phase, quadrature, and permanent phase shift voltages being derived from said exciting windings.

5. In a voltage regulating transformer system for three phase circuits of the type having exciting transformer windings either delta or Y-connected to a source of three phase voltage and a series transformer winding connected in each phase between said source of three phase voltage and a load circuit, means for inducing in each of said series windings a voltage having variable in-phase and quadrature components with respect to the voltage of the phase in which each respective series winding is connected, and means inducing a permanent phase shift voltage in each of said series windings substantially equal in magnitude to the internal impedance voltage drop of the respective series winding for a predetermined load and having a phase angle of about 60° leading the voltage of the respective phase of said source of voltage, said in-phase and quadrature voltages being derived from tapped secondary windings inductively coupled to said exciting windings, and said permanent phase shift voltages being derived from said exciting windings.

6. In a voltage regulating transformer system for three phase circuits of the type having primary windings of an exciting transformer either delta or Y-connected to a three phase source of power and a series transformer having a series winding connected in series with each phase of said source of power, means providing variable in-phase and quadrature voltages connected to exciting windings of said series transformers, said means comprising at least two tapped secondary windings inductively coupled to each of said primary windings, and at least another secondary winding inductively coupled to each of said primary windings and connected to said exciting windings of said series transformer, said another secondary winding providing a voltage in said series windings substantially equal in magnitude to the internal impedance voltage drop in each respective series winding for a predetermined load and having a 60° phase angle leading the voltage of the respective phase of said source of power.

7. A voltage regulating transformer system for three phase circuits comprising a three phase exciting transformer having primary windings connected to a three phase source of power, a series transformer having series windings connected in series between said source of power and a load circuit, first, second, and third secondary windings inductively coupled to each of said primary windings and connected to exciting windings of said series transformer, said first and second secondary windings being tapped and being connected to provide in-phase and quadrature components of voltage to said series windings, said third windings being connected to provide a voltage in each of said series windings substantially equal in magnitude to the internal impedance voltage drop in each respective series winding for a predetermined load and having a 60° phase angle leading the voltage of the respective phase of said source of power.

8. A voltage regulating transformer system for three phase circuits comprising a three phase exciting transformer having first, second and third exciting windings Y-connected to first, second and third phases respectively of a three phase source of power, a first and second tapped secondary winding and a third secondary winding inductively coupled to each of said exciting windings, series transformer means having first, second and third series windings connected respectively, between said first, second and third phases and a load; first, second and third primary windings inductively coupled to said first, second and third series windings, each of said primary windings being connected in series with the first secondary windings of the other two phases respectively to provide a voltage in quadrature with the voltage of the respective phase, the second secondary winding of the respective phase to provide a voltage in phase with the voltage of the respective phase, and the third secondary winding of the adjacent leading phase to provide a voltage substantially equal in magnitude and opposite in phase to the voltage drop in the respective series winding for a predetermined load.

9. The system of claim 8 wherein said secondary windings are Y-connected with each leg of the Y including a first and third secondary winding of the same phase and a second secondary winding of the next leading phase, the first secondary windings being Y-connected.

10. The system of claim 8 wherein said second secondary windings are delta connected, one end of a first

secondary winding being connected to each junction of the second secondary windings of the other two respective phases, the other end of each first secondary winding being connected to the third secondary winding of the next respective leading phase.

11. A voltage regulating transformer system for three phase circuits comprising a three phase exciting transformer having first, second and third exciting windings delta connected to a three phase source of power, a first and second tapped secondary winding and a third secondary winding inductively coupled to each of said exciting windings, series transformer means having first, second and third series windings connected between the junctions of said exciting windings and a first, second and third primary windings inductively coupled to said first, second and third series windings respectively, each of said primary windings being connected in series with two of said second secondary windings to provide a voltage in phase with the voltage of the respective phase to which said primary winding is coupled, one of said first secondary windings to provide a voltage in quadrature with the voltage of said respective phase, and the one third secondary winding to provide a voltage substantially equal in magnitude and opposite in phase to the voltage

drop in the series winding of said respective phase for a predetermined load.

12. The system of claim 11 wherein said secondary windings are Y-connected with each leg of the Y including a second secondary winding of one phase of said delta connected exciting transformer having one end connected to the first secondary winding of the next adjacent leading phase and the other end connected to the third secondary winding of the next adjacent lagging phase, said third secondary windings being Y-connected.

13. The system of claim 11 wherein said first secondary windings are delta connected, the junction of each of said first secondary windings of two phases of said delta connected exciting transformer being connected to one end of the second secondary winding of the other phase, the other end of said second secondary winding being connected to the third secondary winding of the next adjacent lagging phase.

References Cited in the file of this patent

UNITED STATES PATENTS

2,560,385 Dessarzin ---------- July 10, 1951