July 6, 1943. T. C. LENNOX 2,323,716

ELECTRIC CIRCUITS

Filed May 29, 1942 2 Sheets-Sheet 1

Fig. 1.

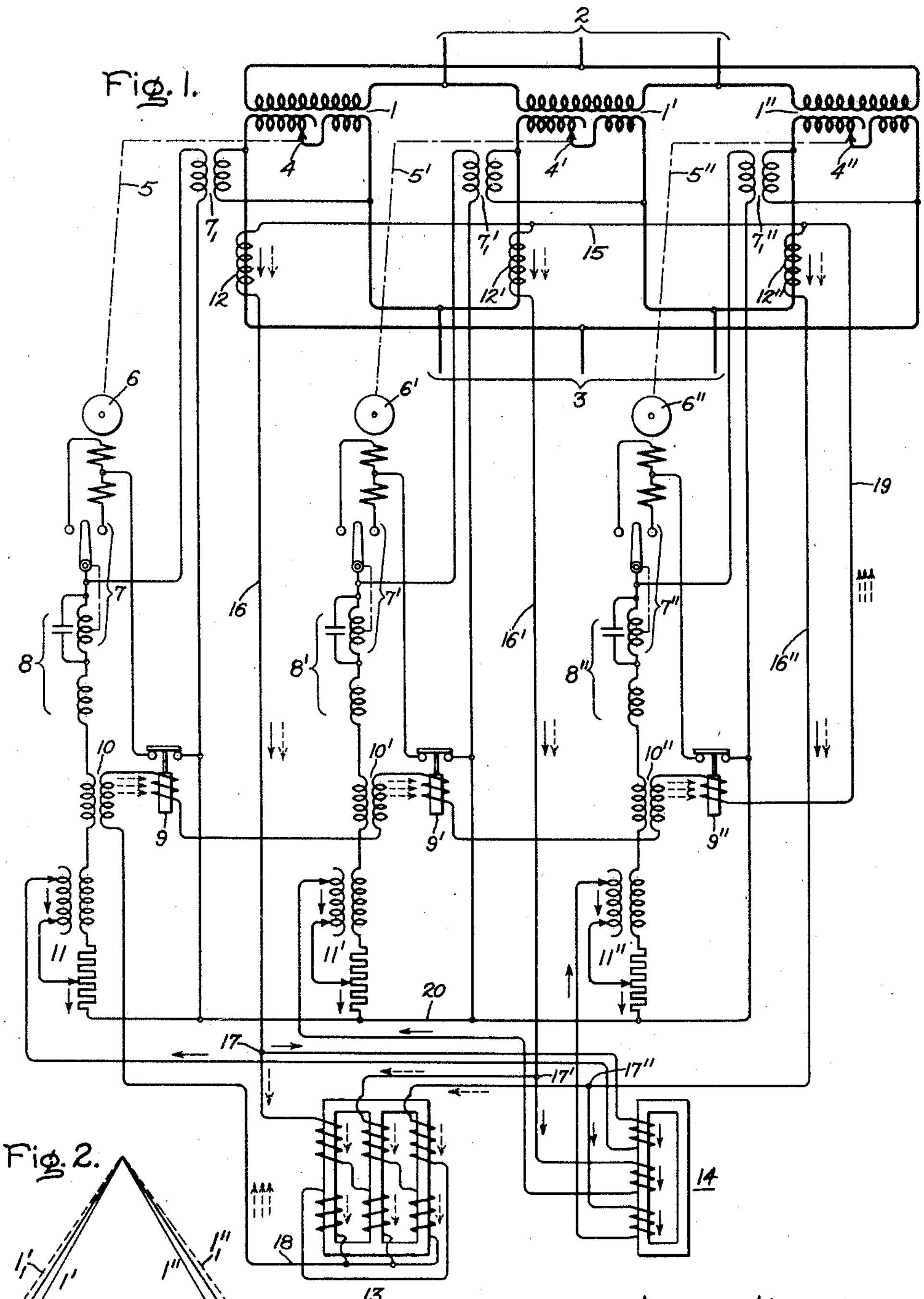
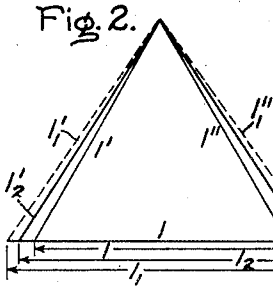


Fig. 2.



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ELECTRIC CIRCUITS

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Fig. 3.

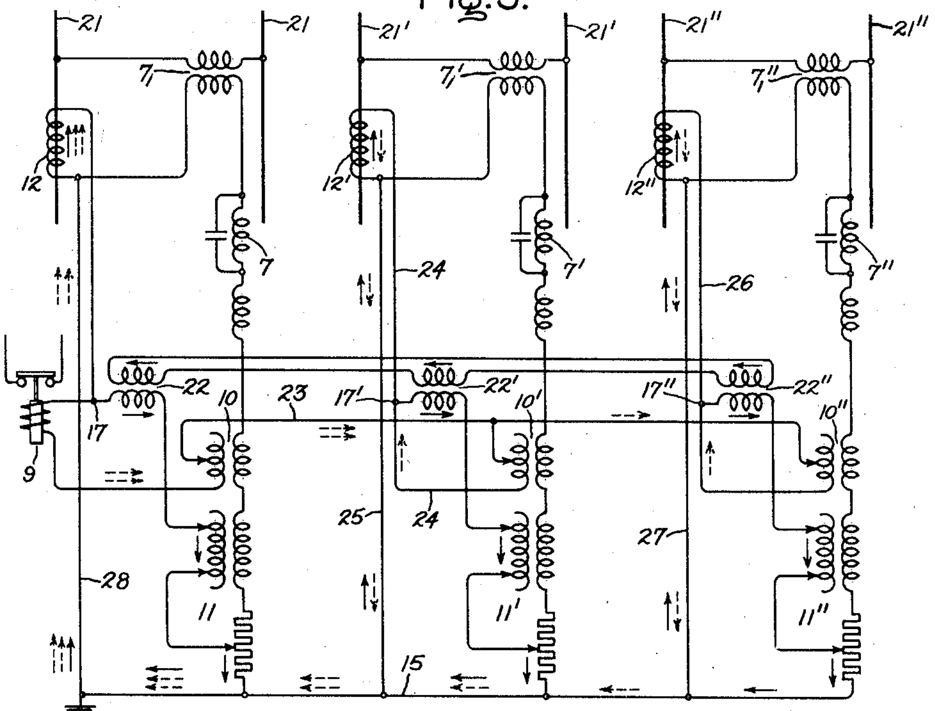
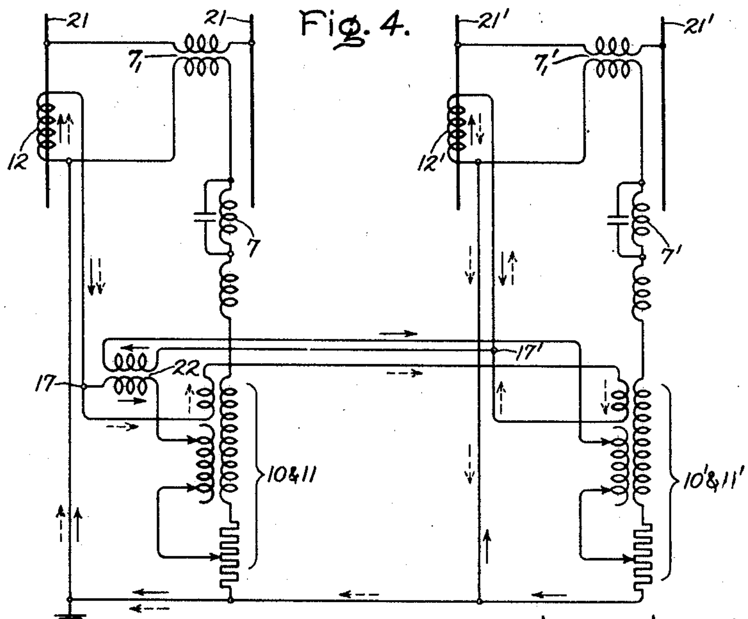


Fig. 4.



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UNITED STATES PATENT OFFICE

2,323,716

ELECTRIC CIRCUIT

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Application May 29, 1942, Serial No. 444,999

16 Claims. (Cl. 171—119)

This invention relates to electric circuits and more particularly to improvements in control circuits for automatic voltage regulators which adjust the voltage of interconnected power circuits.

When power circuits, each of which has its own automatic voltage regulator, are interconnected, a troublesome circulating current often flows in the circuits. This is because the loop circuit comprising two or more power circuits and their interconnections usually has a relatively low impedance so that relatively small unbalanced voltages will cause relatively large circulating currents to flow. These circulating currents ordinarily do no useful work and cause wasteful losses in the system. One way to correct this is to provide a mechanical or positive interconnection between the regulators so that the voltages of the interconnected power circuits must always be the same. However, this is often impractical so that it is very desirable to be able to provide electrical means which will automatically control the regulators so as to minimize circulating currents.

The problem is further complicated when the regulators are provided with line drop compensators. These are current responsive devices which, in effect, overcompound the regulators so as to compensate for the increased voltage drop in the power and load circuits with increases in load with the result that the voltage is maintained constant at some point on the load circuit, such as a so-called center of distribution which is remote from the regulators. Heretofore, these line drop compensators have responded to the total current in their associated power circuits and as the total current includes the circulating current the line drop compensators have also responded to the circulating current. The result has been that the line drop compensators and any circulating current compensators which have responded to circulating current have operated against each other in that when the effect of circulating current on the circulating current compensator has been to lower the voltage held by the regulator the effect of the same current on the line drop compensator has been to raise the voltage of the regulator.

In accordance with the present invention there is provided a new and improved regulator control system in which the power circuit current is separated into its load and circulating current components and only the load component is used to energize the line drop compensator and only the circulating component is used to energize the circulating current compensator.

An object of the invention is to provide a new and improved electric circuit.

Another object of the invention is to provide a new and improved control circuit for automatic voltage regulators.

A further object of the invention is to provide a new and improved system for controlling circulating current in interconnected individually voltage regulated power circuits.

A still further object of the invention is to provide a novel system for segregating the load and circulating components of the current in interconnected circuits.

The invention will be better understood from the following description taken in connection with the accompanying drawings and its scope will be pointed out in the appended claims.

In the drawings, Fig. 1 illustrates diagrammatically an embodiment of the invention in which three single-phase automatic voltage regulating transformers are delta-connected, Fig. 2 is a vector diagram for explaining the operation of Fig. 1, Fig. 3 is a modification in which circulating currents in a plurality of parallel-connected single-phase power circuits are controlled by a system employing as many auxiliary current transformers as there are power circuits, and Fig. 4 is a modification of Fig. 3 in which the number of necessary auxiliary current transformers is reduced to one less than the number of power circuits and in which the circulating current and line drop compensators are physically combined.

Referring now to the drawings and more particularly to Fig. 1, there are shown therein three single-phase variable-ratio transformers 1, 1', and 1'' which serve to interconnect a pair of three-phase circuits 2 and 3. These transformers are shown connected delta-delta and it will be assumed that the circuit 2 is the supply circuit and the circuit 3 is the load circuit. The ratios of these transformers may be varied in any suitable manner and, as shown, they are provided with tap changers 4, 4', and 4'' respectively. The tap changer 4 is operated through any suitable and well-known driving mechanism 5 by means of a reversible motor 6. As the automatic regulators and most of the control for all of the transformers are the same, corresponding elements in the regulators will henceforth be given the same reference numeral and will be distinguished by the appropriate prime and double-prime marks without referring to them specifically in each case. The motor 6 is controlled by a primary electroresponsive device 7 which is shown as consisting essentially of a solenoid winding connected by schematically illustrated mechanical means to actuate the equivalent of a single-pole, double-throw switch. The winding 7 is connected in a voltage sensitive control circuit which is energized by a potential transformer 7_1 which is connected to respond to the voltage of the secondary winding of its associated power transformer.

For improving the operation of the primary controller 7 there is provided a so-called monocyclic ballast 8 consisting of a reactor and a capacitor, one of which is connected in shunt circuit relation with the coil of the primary controller and the other of which is connected in series circuit relation therewith. These elements constitute a simple form of monocyclic circuit having the well-known property of converting constant voltage to constant current, so that with constant voltage applied to the control circuit by the secondary winding of the potential transformer 7′ the operating coil of the primary controller will have constant current regardless of its impedance.

The motor 6 is also energized by the potential transformer 7_1 by connecting the movable one of the control contacts directly to one side of the secondary winding of the potential transformer and connecting a terminal of the motor to the other side of the secondary winding of the potential transformer 7_1 through the contacts of a protective relay 9 whose function will be described later. Also connected in the control circuit is a circulating current compensator 10 and a line drop compensator 11. The former may comprise simply a reactance transformer; that is to say, a transformer having an air gap in its core so as to give a linear relation between its voltage and its abnormally high magnetizing current. The secondary winding of this device is connected in the control circuit and the result is that the voltage which it inserts in the control circuit is substantially in quadrature with the current in its primary winding. The line drop compensator comprises another reactance transformer combined with a rheostat, each of these devices being provided with taps for adjusting the ratio between the current circulated through them and the voltages or voltage drops which they insert in the control circuit.

The current circulated through both of the compensators is derived from a current transformer 12 connected in series with the secondary winding 4 within the delta connection but, as will be explained more fully below, the output current of the current transformer 12 is separated into circulating and load components which are caused respectively to flow through the circulating current and line drop compensators.

Ignoring for the time being the circulating current and line drop compensators, the operation of each automatic regulator is as follows: When the voltage of the secondary winding of the power transformer is at a predetermined normal value, the energization of the winding of the main control element 7 will be such as to keep its contacts open so that the motor 6 will be at rest. If, however, the voltage departs from normal in either direction, the change in energization of the device 7 will be such as to close one or the other of its sets of contacts, thereby to connect the motor 6 across the secondary winding of the potential transformer 7_1 through one or the other of its field windings, thereby to cause the motor to drive the tap-changing means 4 in such a direction as to restore the voltage to normal. The three primary controllers are all set or adjusted to balance at the same voltage but as a practical matter it is impossible to have them all operate their respective contacts at exactly the same value of voltage. The result is that one regulator may produce a tap change before the others do, thereby causing inequality between the phase voltages of the delta-connected system with the result that a circulating current flows therein.

This condition is illustrated in Fig. 2 in which the three full-line vectors 1_1, 1′ and 1″ represent the voltages of the three secondary windings during balanced conditions when all the voltages are equal. Assuming that the regulator for transformer 1 has gotten out of step with the others and has raised the voltage of the secondary winding an amount corresponding to one tap change, the new internal value of voltage of the secondary winding will be the vector 1_1. However, because of the delta connection, this causes the voltage of the other two phases to change to $1_1'$ and $1_1''$. These voltages will not be in phase with the voltage of the primary windings of the transformers and consequently a circulating current is set up in the two deltas which results in impedance voltage drops which reduce voltage 1_1 to 1_2 and reduce $1_1'$ to $1_2'$ and reduce $1_1''$ to $1_2''$ as shown in the diagram. The impedance voltage due to the circulating current in each phase will be equal to (1_1-1_2) and will have the same phase position in all three transformers because it is set up by the same circulating current.

It will be observed from the above vector diagram that although the tap change was made by tap changer 4, the voltage of its winding was not increased by the full amount represented by one tap and that the voltages of the other two phases are increased from their original values to the sub-2-values, although no tap change has occurred in them. Consequently, a tap change is less likely to follow by tap changers 4′ and 4″ and a further tap change may be necessary by tap changer 4 in order to give the required correction in case of low voltage on the load circuit 3. Thus the effect of the circulating current is to move the tap-changing equipments further apart on the different transformers or phases.

The segregation of the load and circulating components of the output currents of the three current transformers is accomplished by means of a pair of inductive reactance devices 13 and 14. These are three-phase devices and they are connected effectively in parallel with each other to the three-phase output circuit of the three current transformers. Device 13 is a so-called zigzag transformer which has relatively low reactance with respect to the circulating current component and relatively high reactance with respect to the load current component, whereas device 14 which is a simple reactor has the opposite characteristics in that it has high reactance with respect to the circulating current component and low reactance with respect to the load current component. The result is that substantially all of the circulating current component flows through the device 13 and substantially all of the load current component flows through the device 14.

As shown, the secondary windings of the three current transformers are connected to a common neutral conductor 15 and their remaining terminals are connected by means of conductors 16, 16′, and 16″ to junction points 17, 17′ and 17″. The zigzag transformer 13 has a neutral 18 which is connected to the neutral 15 of the current transformer secondary windings by a conductor 19 in series with which are connected the primary windings of the three circulating current compensators 10 and the operating windings of the three protective relays 9. The three windings of the reactor 14 are connected respectively to the junctions 17, 17', and 17'' and their remaining terminals are connected to a neutral conductor 20 through the respective line drop compensators 11, 11' and 11''.

Specifically, the zigzag transformer 13 comprises a three-legged core similar to the core of a three-phase transformer. Mounted on each leg is a pair of windings and all six windings have the same number of turns. Serially connected between each of the junction points 17, 17' and 17'' and the neutral 18 are two of the windings which are on different legs. They are so connected that their instantaneous magnetomotive forces are in opposite directions with respect to the legs upon which they are mounted. The entire connection is symmetrical. The result is that with respect to a symmetrical three-phase voltage impressed between the junctions 17, 17' and 17'' the leg voltages between each of these junctions and the neutral 18 will be the vector difference between the voltages of the two windings serially connected between each junction and the neutral. These leg voltages will, of course, not be in phase with the voltage of any one of the windings but the major components of the currents in the two windings on each leg will be in phase with each other so that the core will be magnetized like a conventional three-phase transformer core. Consequently, the device will act like a three-phase reactor with respect to a three-phase voltage and therefore the three-phase current will be limited to an insignificant value corresponding to the magnetizing current of a reactor. However, if the currents in all six windings are in phase with each other, which would be the result if the leg voltages between the junctions 17, 17' and 17'' and the neutral 18 were all in phase with each other, then the magnetizing effects of the two windings on each leg would be exactly equal and opposite to each other so that the core would be unmagnetized and the device would have substantially zero reactance.

The device 14 has all of its windings mounted on the same magnetic circuit so that in-phase currents in the three windings will produce cumulative magnetic effects, thereby strongly to magnetize the core with the result that the device has a high reactance with respect to such currents. On the other hand, if the three windings carry symmetrical three-phase currents, then the vector sum of their magnetizing effects is zero, so that the core is unmagnetized and the device has very low reactance with respect to such currents.

In a polyphase system of currents whose symmetry is disturbed by a circulating current, the resulting unsymmetrical three-phase system is resolvable into what are sometimes called positive and zero sequence components. The zero sequence component is the same in all the phases and therefore, as its name implies, it has no phase sequence. This zero sequence component therefore corresponds to the circulating current, and the remaining positive sequence component is symmetrical and it will be seen that it corresponds to the load or power component of the current.

In Fig. 1 the full-line arrows represent the load or positive sequence components of the current output of the secondary windings of the current transformers, and the dashed arrows indicate the circulating or zero sequence components of this current. It should be understood, however, that these arrows do not represent accurately the vector relations between the load or positive sequence currents because they form a symmetrical three-phase system and consequently they are vectorially 120 degrees apart. As will be seen, the two currents of each phase flow together from the windings 12 through the conductors 16 to the junction points 17. At these junction points they are offered the choice of two effectively parallel paths, one through the device 13 and the other through the device 14. As has been previously explained, the impedance of the device 13 is very low with respect to the zero sequence currents and is very high with respect to the positive sequence currents and, conversely, the impedance of the device 14 is very low with respect to the positive sequence currents and very high with respect to the zero sequence currents. The result is that the zero sequence or circulating currents all flow through the zigzag transformer 13 and the positive sequence or load component currents all flow through the device 14. The zero sequence currents combine in the neutral 18—19 and all flow through the circulating current compensators and the relays 9 and back to the neutral 15. This connection of the circulating current compensators is preferable to connecting each one of them in series with the respective input phases of the zigzag transformer 13 because obviously the current in the neutral 18—19 is three times as large as the current in the three input phases, as the circulating currents all being in phase add algebraically in the neutral. As indicated by the solid arrows, the positive sequence currents when they leave the windings of the device 14 flow respectively through the line drop compensators and then back to the neutral 20 where they add up to zero so that the neutrals 20 and 15 need not be interconnected.

The device 14 is not so important when there is no connection between the neutrals 15 and 20 because the absence of such connection will in itself prevent the flow of zero sequence current in the line drop compensators. However, when these neutrals are grounded or otherwise interconnected, then the device 14 is necessary to keep the zero sequence current out of the line drop compensators.

The resistance and reactance elements of the line drop compensators are adjusted so that the voltages which they insert in the circuit of the primary controller 7 are proportional respectively to the resistance and reactance voltage drops produced by the actual load current flowing in the power system between any particular point on the load circuit 3 and the corresponding secondary winding of the power transformers in the delta connection. Because of the fact that none of the circulating current flows through the line drop compensators, the amount of line drop compensation will be unaffected by the presence of circulating current which is a highly desirable result. This is especially true because in most systems the internal impedance of the delta or power transformer winding connections is low compared with the impedance of the load circuit 3 and as the circulating current is confined to the delta and does not get out into the load circuit, it obviously has little or no effect on the correct amount of line drop compensation.

Similarly, as none of the power current flows through the circulating current compensators, they respond only to circulating current and produce no compensating voltages when there is no circulating current. The voltages produced by the circulating current compensators have the same phase in all three of the regulator control circuits. This voltage will be in phase with and additive algebraically with respect to the voltage of the potential transformer or the power transformer whose voltage is above the voltage of the others, thereby to cause the regulator control element to act as though the voltage is too high and therefore lower the voltage. As the voltages of the other two potential transformers have 120-degree phase displacement with respect to the high voltage one of the three, the circulating current compensator voltages in those control circuits will add vectorially to their respective potential transformer voltages and the resultant will in both cases be lower than the voltage of their respective potential transformers, thereby causing the regulators to raise the voltage of the low voltage power transformers. In this manner the presence of circulating current automatically causes effects in the regulator control circuits which are such as to change the power circuit voltages in a manner to reduce the circulating current to zero.

The relays **9** are adjusted to open their contacts when the value of circulating current reaches a predetermined and excessive amount. Therefore, if for any reason the circulating current compensators do not operate properly, the relays **9** will open their contacts and thereby will cause the motors **6** to be deenergized so as to prevent the regulators from being driven any further apart and thus causing any further increase in circulating current.

In Fig. 3 there are three power circuits **21**, **21′** and **21′′** which instead of being connected in delta, as are the power transformers **1**, **1′** and **1′′** of Fig. 1, may be considered as being connected in parallel with each other by any suitable connecting means (not shown). For the sake of simplicity, the actual voltage regulating means for these circuits have not been shown and only the control circuits for the regulators have been shown. These control circuits are similar to those shown in Fig. 1 in that they each comprise a potential transformer 7_1 connected to measure the voltage of the power circuit and a current transformer **12** connected to measure the current in the circuit. The potential transformer circuit includes the operating element of the main control device **7** in series with the circulating current compensator **10** and the line drop compensator **11** and the current transformer **12** serves to supply current for the two compensators.

However, in Fig. 3 the means for segregating the load and circulating components of the current in current transformers is different. Thus, there are provided three auxiliary current transformers **22**, **22′** and **22′′**, all of whose secondary windings are connected in series. The primary windings of these current transformers are connected in series respectively with the line drop compensators. The effect of the auxiliary current transformers is to force a fixed ratio of current in the line drop compensators. This is one of the characteristics of the load current in parallel-connected alternating-current circuits because the circulating current, as its name implies, does not flow through the load but only circulates through the paralleling connections and thus what it adds to the current in one or more of the circuits it subtracts equally from the current in the other circuits so that the average current remains unchanged. Thus, the presence or absence of circulating current does not affect the ratio of load currents in the parallel-connected circuits.

In the simplest case in which all of the parallel power circuits share the load equally, the current transformers **12** will have the same ratio and the current transformers **22** will have the same ratio. The series connection of the secondary windings of the current transformers **22** means that they all carry the same current and consequently by reason of the close coupling between the primary and secondary windings of each of them the primary windings tend to carry the same current. In the case where there is no circulating current, all of the output current from the current transformers **12** will then flow through the primary windings of the auxiliary current transformers **22** and through the line drop compensators, as should be the case. If, however, the voltages of the power circuits become unequal, then the circulating current which is additive in one or more of the power circuits and subtractive in the others will be prevented from flowing through the line drop compensators by the auxiliary current transformers **22** which prevent a change of the ratio of currents through their primary windings so that all of the circulating current is forced through the relays **9** and the circulating current compensators.

The solid and dashed arrows indicate the operation of the circuit for the case where the voltage of circuit **21** is higher than the voltages of the other two circuits. In this case there are two units of circulating current which flow in the current transformer **12** and down to the junction point **17**. They then flow through the relay **9** and through the circulating current compensator **10** and then on through an equalizing conductor **23**, one unit of circulating current leaving the conductor **23** and flowing through the circulating current compensator **10′** in what will be noted to be the opposite direction to that in which it flows through the compensator **10**. This unit of circulating current then flows through a conductor **24** and through the current transformer **12′** and through a conductor **25** to the neutral connection **15**. The remaining unit of circulating current flows on through the conductor **23** and flows through the circulating current compensator **10′′** in the same direction as the first unit flowed through the compensator **10′**. It then flows up through a conductor **26** to the current transformer **12′′** and down to the neutral connection **15** through a conductor **27**, the two units of circulating current then recombining and flowing up through a conductor **28** to the current transformer **12**. This completes the entire circuit for the circulating current components in the regulator control circuits. The flow of the power component currents, which are indicated by the solid arrows, is obvious from the drawings.

In Fig. 4 the circuit is simplified and its cost reduced by reducing the number of auxiliary current transformers. For the sake of simplicity, only two power circuits are shown and consequently only one auxiliary current transformer is necessary. As shown, each of the two windings of this current transformer is connected respectively to the junctions **17** and **17′** and the remaining terminals of the two windings are connected respectively to the line drop compensators **11**. By means of the close coupling between the windings of the auxiliary current transformers their ratio of currents is fixed, thereby, as previously explained, forcing the load components of the current in the main current transformers 12 to flow through the line drop compensators. These currents, as in the previous figures, are indicated by the solid arrows. The remaining circulating current components therefore must flow through the circulating current compensators 10, as indicated by the dashed arrows. In this figure the reactance transformers constituting the circulating current compensator 10 and the reactance element of the line drop compensator 11 have a common secondary winding. In this manner these devices may conveniently be physically combined into a single structure, although functionally they are still separate devices.

If there are more than two parallel circuits in the modified system of Fig. 4, all of the control circuits except one will have auxiliary current transformers 22 with their secondary windings connected in series and the remaining control circuit, which has no auxiliary current transformer, will have its line drop compensator connected into the series circuit of these secondary windings in the same manner in which the line drop compensator 11' of Fig. 4 is connected in series with the secondary windings of the current transformer 22.

While there have been shown and described particular embodiments of this invention, it will be obvious to those skilled in the art that various changes and modifications can be made therein without departing from the invention and therefore it is aimed in the appended claims to cover all such changes and modifications as fall within the true spirit and scope of the invention.

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

1. In combination, a plurality of alternating-current power circuits, separate voltage regulating means for automatically maintaining the voltage of said circuits substantially the same, said circuits being interconnected so that inequality in their voltage causes a circulating current to flow therein, a common load for said circuits, means for deriving a current from each of said circuits which is proportional to the load component of the total current therein and which is independent of the circulating component of the total current therein, a separate line drop compensator for each of said voltage regulating means, and means for energizing each line drop compensator with the load component current derived from its associated power circuit.

2. In combination, a plurality of alternating-current power circuits, separate voltage regulating means for automatically maintaining the voltage of said circuits substantially the same, said circuits being interconnected so that inequality in their voltage causes a circulating current to flow therein, a common load for said circuits, a separate means associated with each of said circuits for deriving a compensating current therefrom which is proportional to the total current in its associated circuit, auxiliary means for separating each compensating current into two components which are proportional respectively to the load and circulating current components of the total current in its associated power circuit, separate line drop compensating and circulating current compensating means for each voltage regulating means, means for energizing each line drop compensating means in accordance with the load component of the compensating current derived from its associated power circuit, and means for energizing each circulating current compensating means in accordance with the circulating component of the compensating current derived from its associated power circuit.

3. In combination, a plurality of independently variable voltage interconnected alternating-current power circuits having a common load, means including a separate control circuit responsive to the voltage of each power circuit for maintaining its voltage substantially the same as the voltage of the others, a separate line drop compensator in each of said control circuits, a separate current transformer in each of said power circuits, and means for interconnecting said current transformers with each other and with said line drop compensators in such a manner that each line drop compensator carries a current which is proportional to the load component of the current in its associated power circuit and which is independent of any circulating current which may be present in said power circuits.

4. In combination, a plurality of independently variable voltage interconnected alternating-current power circuits having a common load, means including a separate control circuit responsive to the voltage of each power circuit for maintaining its voltage substantially the same as the voltage of the others, a separate line drop compensator in each of said control circuits, a separate circulating current compensator in each of said control circuits, a separate current transformer in each of said power circuits, each of said current transformers having a single secondary winding, and means for interconnecting said secondary windings so as to obtain separate currents proportional respectively to the load and circulating components of the total currents in said power circuits, said line drop compensators and circulating current compensators being connected to be energized respectively by the appropriate one of said currents.

5. In combination, a plurality of interconnected electric power circuits having a common load circuit, separate automatic voltage regulators for said circuits adjusted to maintain said voltages substantially equal, and means responsive to the existence of more than a predetermined amount of circulating current in said power circuits as a result of a difference in the voltage of said power circuits for automatically preventing further operation of said regulators until the value of said circulating current is less than said predetermined value.

6. In combination, a plurality of interconnected power circuits having individual automatic voltage regulating means each of which includes a circulating current compensated line drop compensated primary control circuit, a conventional current transformer in each power circuit, multiple circuit means for connecting the secondary winding of each current transformer to the regulator control circuit of its associated power circuit, electromagnetic means connected to said multiple circuit means for segregating the load and circulating current components of the secondary winding current of said current transformers, and separate compensating means in each of said control circuits energized respectively by the load and circulating current components derived from their associated power circuits.

7. In combination, a polyphase circuit having combined positive and zero sequence currents, means having relatively low impedance to positive sequence currents and relatively high impedance to zero sequence currents, means having relatively high impedance to positive sequence currents and relatively low impedance to zero sequence currents, said two means being connected in parallel circuit relation to said circuit so as to separate said positive and zero sequence currents, and electroresponsive means connected to be energized by at least one of said sequence currents.

8. In combination, a polyphase circuit having combined positive and zero sequence currents, a separate current transformer for each phase of said circuit, the secondary windings of said current transformers being star-connected, a zigzag transformer, a reactor having a star-connected winding on a single magnetic circuit, said zigzag transformer and star-connected reactor being connected to be energized in parallel circuit relation by a star-connection of the secondary windings of said current transformers, a connection between the neutral of said secondary windings and the neutral of said zigzag transformer whereby zero sequence current flows between said neutrals and positive sequence current flows in said reactor windings, and separate electroresponsive devices connected to be energized respectively by said zero sequence and positive sequence currents.

9. In combination, a polyphase system having a plurality of phases which are mesh-connected, each of said phases having its own automatic voltage regulator, each of said regulators having its own line drop compensator and circulating current compensator, means for separating the current in each of said phases into load and circulating current components, and connections for energizing said compensators with the appropriate current components of their corresponding phases.

10. In combination, a polyphase system having a plurality of variable voltage phases which are mesh-connected, separate regulating means responsive respectively to the voltage of each of said phases for automatically maintaining substantial equality between said voltages, an individual line drop compensator and an individual circulating current compensator for each of said regulating means, a separate current transformer connected in each of said phases, and separate polyphase impedances connected in parallel circuit relation with each other to said current transformers, one of said impedances permitting only zero sequence current to flow therethrough and the other of said impedances permitting only positive sequence currents to flow therethrough, said line drop compensators being connected to be energized respectively by the phase currents of the impedance which permits only positive sequence currents to flow, said circulating current compensators being connected to be energized by the current in the impedance which permits only zero sequence currents to flow.

11. In combination, a plurality of parallel-connected alternating-current power circuits each of which is provided with its own line drop compensated voltage regulator control circuit, means for energizing the respective line drop compensators of said control circuits in accordance with a predetermined ratio of load currents in their associated power circuits which is substantially independent of circulating current in said circuits, circulating current compensating means in each of said control circuits, and means for energizing each of said circulating current compensating means in accordance with the circulating current in its associated power circuit.

12. In combination, a plurality of parallel-connected power circuits, separate automatic voltage regulating means for each of said circuits, separate line drop compensating means for each of said regulating means, and means for energizing said line drop compensating means in accordance with the average current in said power circuits.

13. In combination, a plurality of parallel-connected power circuits, separate automatic voltage regulating means for each of said circuits, separate line drop compensating means for each of said regulating means, means for energizing said line drop compensating means in accordance with the average current in said power circuits, separate circulating current compensating means for each regulating means, and means for energizing each circulating current compensating means in accordance with the difference between the current in its associated power circuit and said average current.

14. In combination, a plurality of parallel-connected alternating-current power circuits each of which is provided with its own line drop compensated voltage regulator control circuit, a separate current transformer in each of said power circuits for energizing the line drop compensator of its regulator control circuit, separate auxiliary transformers having their primary windings connected respectively in series with the secondary windings of said current transformer, the secondary windings of said auxiliary transformers being connected in series, an equalizer connection between said control circuits, and circulating current compensating means for each of said control circuits energized in accordance with the current in said equalizer connection.

15. In combination, a plurality of parallel-connected alternating-current power circuits, individually-controlled automatic voltage regulating means for each power circuit, a separate line drop compensator for each of said regulating means, a separate current transformer in each of said circuits, and means energized by said current transformers and including at least one less auxiliary current transformer than there are parallel-connected power circuits for energizing said line drop compensators in proportion to the average current in said power circuits.

16. In combination, a plurality of parallel-connected alternating-current power circuits, individually controlled automatic voltage regulating means for each power circuit, a separate line drop compensator for each of said regulating means, a separate main current transformer in each of said circuits, means energized by said main current transformers and including at least one less auxiliary current transformer than there are parallel-connected power circuits for energizing said line drop compensators in accordance with the average current in said power circuits, a separate circulating current compensator for each of said regulating means, and means for energizing each of said circulating current compensators in accordance with the difference between said average current and the current in its associated main current transformer.

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