

Nov. 27, 1956

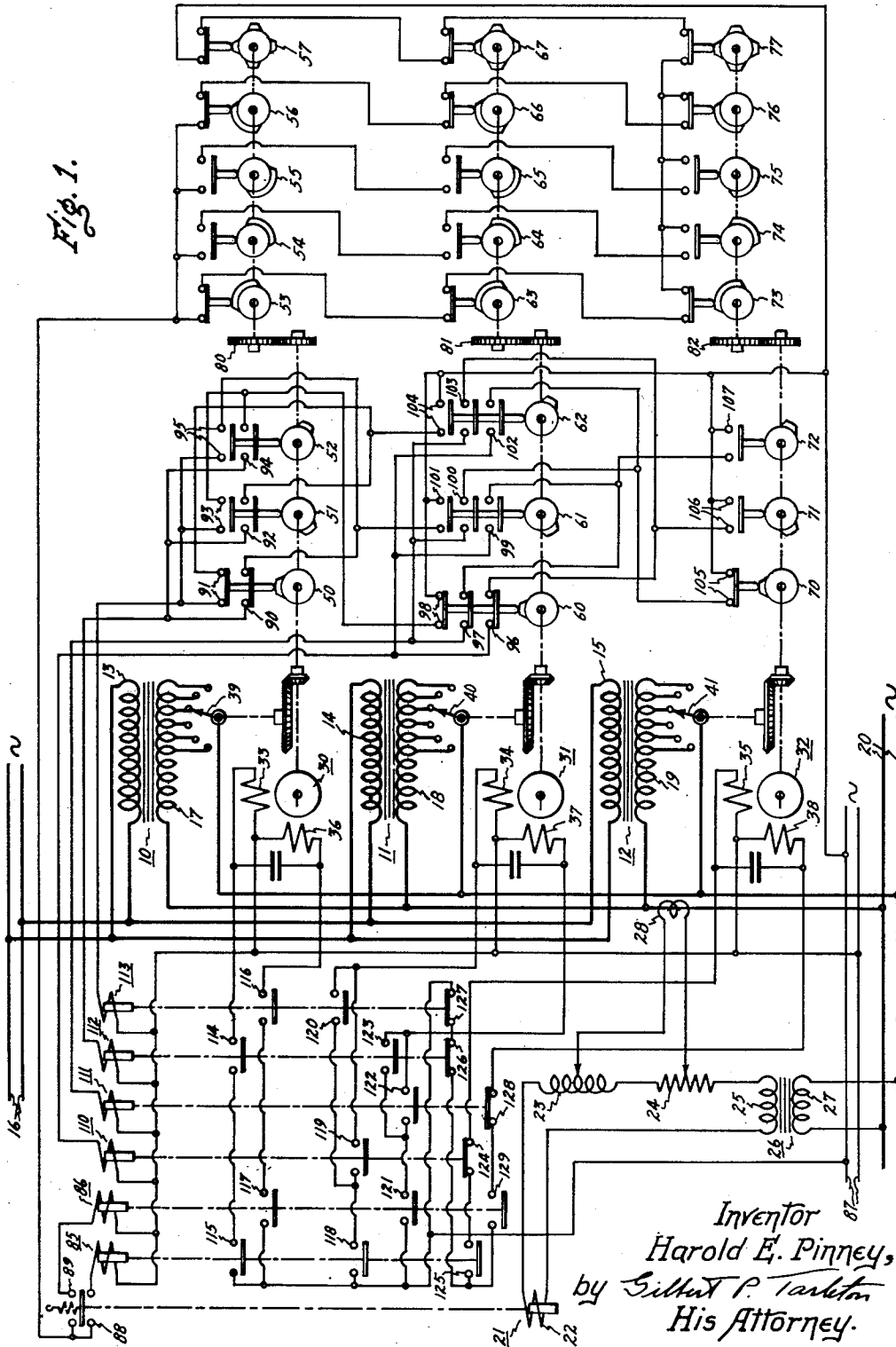
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PARALLEL OPERATION OF TAP CHANGING TRANSFORMERS

Filed Oct. 28, 1955

2 Sheets-Sheet 1



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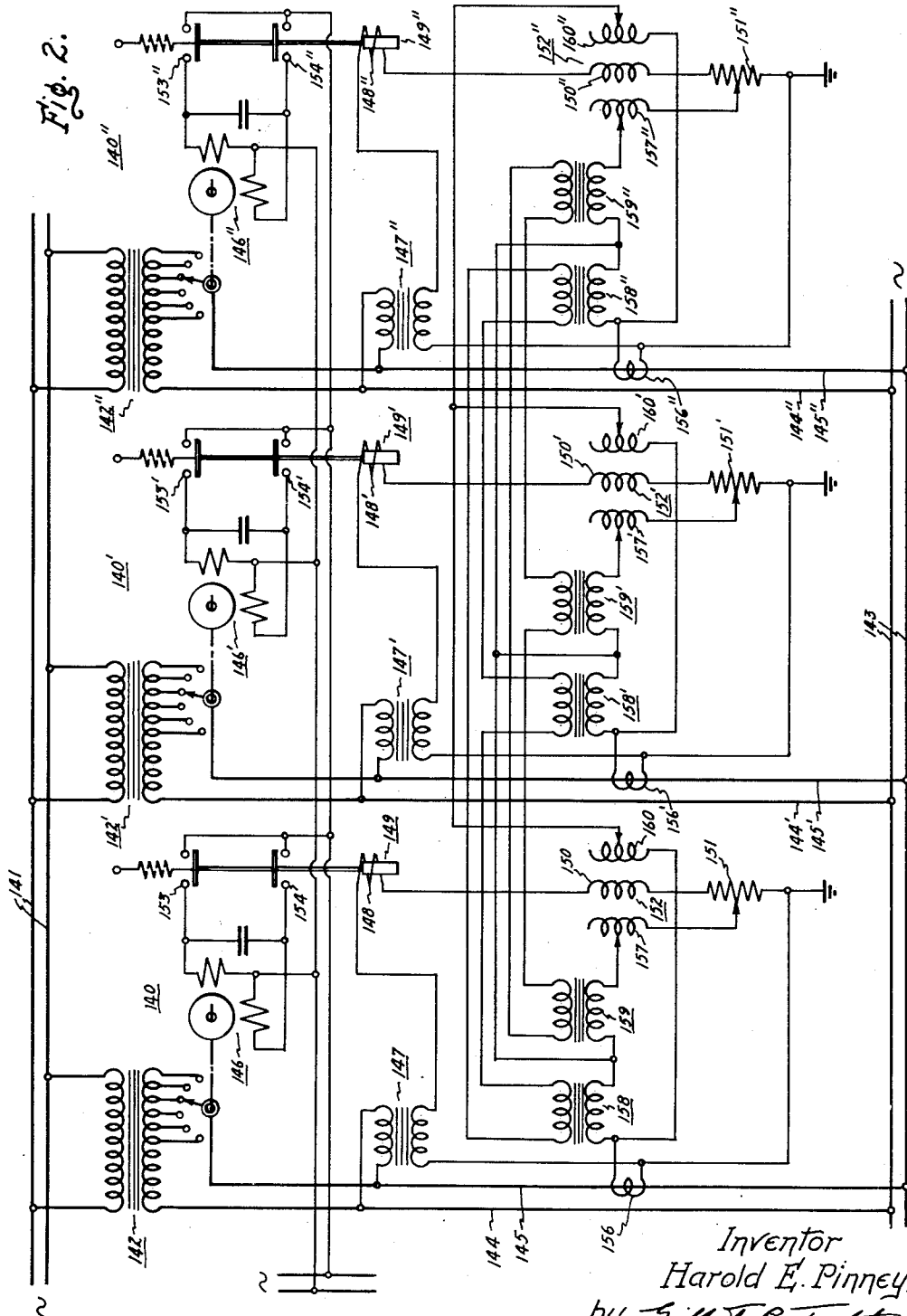
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2 Sheets-Sheet 2



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PARALLEL OPERATION OF TAP CHANGING TRANSFORMERS

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20 Claims. (Cl. 307—58)

This invention relates to automatic parallel operation of alternating current power supply systems, and more in particular to means for sequentially operating the tap changing mechanisms of a plurality of parallel connected tap changing transformer systems such as voltage regulating transformer systems or load tap changing transformer systems.

In the past, various circuits have been employed for interconnecting a plurality of tap changing transformer systems for parallel operation. In the one type of circuit, such as disclosed in U. S. Letters Patent No. 2,322,249 which issued on an application of S. Minneci and is assigned to the present assignee, and also No. 2,323,716 which issued on an application of T. C. Lennox and is also assigned to the present assignee, the transformer systems are interconnected in such a manner that the motor drive control for these tap changing mechanisms maintains a predetermined ratio between the load current carried by each of the transformers and also minimizes circulating current flow between the transformers. In this type of circuit, at the end of any tap changing operation, all of the tap changing mechanisms have made essentially the same number of tap changes, even though the changes may not have been made simultaneously due to differences in response time of the various systems.

In another type of circuit, such as disclosed in U. S. Letters Patent No. 1,970,389 which issued on application of S. Minneci and is also assigned to the present assignee, a raise or lower initiating signal from a common automatic control is given to only one of the transformer systems, called the master system. When a voltage change is called for, this initiating signal is delivered to the master system, which makes a single tap change. Auxiliary switches on the master system then give the signal to the remaining or follower systems to each make a single tap change to catch up with the master system. The tap change of the follower systems takes place regardless of whether or not the tap change by the master unit has corrected the load voltage to eliminate the initiating signal.

In both of the above circuits, means are provided to keep the tap changing mechanisms of the parallel systems in step as an operating condition in order to reduce the flow of circulating currents between the systems. In some applications, however, it is desirable to obtain voltage corrections in smaller increments than that obtainable by full tap changes being made on all of the parallel systems. It has now been found that the smaller voltage increments may be obtained by providing means for operating the transformer systems out of step, that is, by permitting operating conditions to exist wherein the transformer systems may be one tap apart. While this type of operation results in a certain amount of circulating current, this disadvantage is not too great due to the fact that the circulating current is almost purely reactive, and also the disadvantage may be greatly outweighed by the

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desirability of holding the variations of regulator voltage within smaller limits.

It is therefore an object of this invention to provide means for operating parallel connected tap changing systems out of step in order to provide voltage corrections in smaller increments than obtainable when all the systems are in step.

Another object is to provide means for sequentially operating the tap changing mechanisms of a plurality of parallel connected tap changing systems, wherein the taps of the systems may be one step apart, in order to provide voltage corrections in smaller increments that are obtainable by keeping all of the systems in step as an operating condition.

Briefly stated, my invention provides means for parallel connecting a plurality of tap changing transformers wherein the transformers may be operated one tap change apart in order to permit voltage corrections of smaller increments at the expense of somewhat increased circulating currents between the transformers. Thus in a power system having parallel connected tap changing transformers variable in increments of V volts, my invention provides means for varying the system voltage in increments of substantially V/N volts in response to load circuit voltage variations, where N is the number of parallel connected transformers. In its broad aspects, my invention provides means for sequential operation of the tap changing mechanisms of the transformers, so that sufficient tap changes are made to bring the system load voltage within the desired voltage band, regardless of whether or not tap changes have been made on all of the parallel connected transformers. As has been previously stated, the disadvantage of an increase in circulating currents from such type of operation may be greatly outweighed, in some applications, by the desirability of providing voltage correction in smaller increments, and the effect of the disadvantage of the circulating current is not too great, since the circulating currents are almost purely reactive.

In one embodiment of my invention, assuming three tap changing transformers are to be parallel connected, I designate one of the transformers as the master unit, and a raise or lower initiating signal from a common automatic control is given to this master unit only. In this system I provide a plurality of relays and contacts on cams driven by the individual motor drive controls of the tap changing transformers connected in such a manner that the tap changing mechanisms are operated sequentially, and if one tap change by the master unit corrects the system voltage, then no further operation of the tap changing mechanisms occurs. If the system voltage is not corrected by the tap change on the master unit, then one of the other transformers, designated as the first follower unit, will make a tap change. If the tap changes on the master unit and first follower unit do not correct the system voltage, then the remaining transformer, designated as the second follower unit, will make a tap change. After the tap change has been made on each of the three transformers, the sequence is ready to be repeated until such time as the system voltage is corrected.

In another embodiment of my invention, I provide a parallel interconnected tap changing transformer system, similar to that disclosed in the previously mentioned Minneci Patent No. 2,322,249 and the Lennox Patent No. 2,323,716, wherein each of the tap changing transformers is provided with a voltage regulating relay and a drop line compensator. In this embodiment of my invention, sequential operation of the tap changing transformer mechanisms is provided by adjusting the circulating current component of the line drop compensator voltage, and by proper coordination of the adjustments of

this circulating current compensating voltage and the voltage level and voltage band width settings of the voltage regulating relays on all of the parallel connected units.

My 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.

Fig. 1 is a circuit diagram of a system for parallel connecting a plurality of tap changing transformers and illustrating one embodiment of my invention.

Fig. 2 is a circuit diagram of a system for interconnecting a plurality of tap changing transformers and illustrating another embodiment of my invention.

Referring now to the drawings, and particularly to Fig. 1, therein is shown three tap changing transformers 10, 11 and 12 having their primary windings 13, 14 and 15 respectively connected in parallel to alternating current power supply lines 16, and their tapped secondary windings 17, 18 and 19 respectively connected in parallel to alternating current load lines 20. The designation of these windings as primary and secondary windings is for the sake of convenience in terminology, and it is not intended thereby to limit the scope of this invention. It will therefore be understood that the power flow may be either from lines 16 to lines 20, or from lines 20 to lines 16.

The tap changing transformer 12 will be hereinafter referred to as the master transformer, the tap changing transformer 11 will be hereinafter referred to as the first follower transformers, and the tap changing transformer 10 will be hereinafter referred to as the second follower transformer. A voltage regulating relay circuit of the conventional type is provided comprised of a voltage regulating relay 21, having a coil 22 connected in series with a line drop compensator comprised of a reactor 23 and a resistor 24, and the secondary winding 25 of a potential transformer 26. The primary winding 27 of a potential transformer 26 is connected across the load lines 20. A current transformer 28 has its secondary winding inductively coupled to a lead to the load lines 20, and the secondary winding of the current transformer 28 is connected between a variable tap on the reactor 23 and the variable tap on the resistor 24 of the line drop compensator.

Tap changing motors 30, 31 and 32 having voltage raising windings 33, 34 and 35 respectively and voltage lowering windings 36, 37 and 38 respectively are mechanically coupled to the arms 39, 40 and 41 respectively of the secondary windings of transformers 10, 11 and 12 respectively. Tap changing motor 30 is mechanically coupled to drive cams 50, 51, 52, 53, 54, 55, 56 and 57, tap changing motor 31 is mechanically coupled to drive cams 60, 61, 62, 63, 64, 65, 66 and 67, and tap changing motor 32 is mechanically coupled to drive cams 70, 71, 72, 73, 74, 75, 76 and 77. The cams 50, 51, 52, 60, 61, 62, 70, 71 and 72 each have three positions corresponding to adjacent tap positions of the arms of the respective transformers. Similarly the cams 53 to 57, 63 to 67 and 73 to 77 each have four positions corresponding to adjacent tap positions of the respective arms of the tap changing transformer. This arrangement provides repetition of the cycle of cam action on the cams 50 to 52, 60 to 62 and 70 to 72 after every three tap changes in the same direction on the respective tap changing transformer, and repetition of the cycle of cam action on the cams 53 to 57, 63 to 67 and 73 to 77 after every four tap changes in the same direction on the respective tap changing transformer. In the arrangement shown in Fig. 1 this action is provided by means of gear drive 80, 81 and 82 having a ratio of three to four between the cams 50 to 52 and 53 to 57, cams 60 to 62 and 63 to 67, and the cams 70 to 72 and 73 to 77 respectively. It will be obvious to one skilled in the art that other mechanical arrangements may also be provided to achieve the same cam action.

The coil of a master "raise" relay 85 and the coil of a

master "lower" relay 86 are connected to alternating current supply lines 87 by way of the raise contacts 88 and lower contacts 89 respectively of the voltage regulating relay 21 and a series parallel arrangement of the cam contacts of cams 53 to 57, 63 to 67 and 73 to 77. Each of these cams has a single pair of contacts, and the contacts are connected in order to prevent the possibility of any of the tap changing motors for making a tap change on its respective tap changing transformer that is more than one step apart from the tap position on the other tap changing transformers. The contacts of cams 53, 63 and 73 are connected in series, the contacts of cams 54, 64 and 74 are connected in series, the contacts of cams 55, 65 and 75 are connected in series, the contacts of cams 56, 66 and 76 are connected in series, and the four series circuits are connected in parallel. This series parallel contact combination is connected in series with the contacts of cams 57, 67 and 77. In the position of the cams shown in Fig. 1 the contacts of cams 53, 56, 63, 66, 73 and 76 are closed. In the next adjacent tap position corresponding to counterclockwise rotation of these cams, the contacts of cams 53, 54, 63, 64, 73 and 74 are closed. In the second adjacent tap position corresponding to counterclockwise rotation of these cams, the contacts of the cams 54, 55, 64, 65, 74 and 75 are closed. In the third adjacent tap position corresponding to counterclockwise rotation of these cams, the contacts of cams 55, 56, 65, 66, 75 and 76 are closed. The contacts of cams 57, 67 and 77 are closed at all times when the arms of the tap changing transformer are on position, and open when these arms are between positions.

It may be readily seen that when the cams of motors 30, 31 and 32 are on either the same position or on positions only one tap apart, the master relays 85 and 86 may be energized upon bridging of the contacts of the voltage regulating relay. If the tap position of one of the transformers is separated from a tap position of any of the other transformers by more than one tap, however, the master relays 85 and 86 cannot be energized by bridging of the contacts of the voltage regulating relay.

The cams 50, 51 and 52 each have two contacts, 90 and 91, 92 and 93, and 94 and 95 respectively. The cams 60, 61 and 62 each have three pairs of contacts 96, 97, and 98, 99, 100 and 101, and 102, 103 and 104 respectively. The cams 70, 71 and 72 each have a single pair of contacts 105, 106 and 107 respectively. The cams are arranged such that the contacts of cams 50, 60 and 70 are closed in one position when the tap changing transformers are in step, the contacts of cams 51, 61 and 71 are closed in the next adjacent tap position corresponding to clockwise rotation of the cams, and the contacts of cams 52, 62 and 72 are closed in the second adjacent tap position corresponding to clockwise rotation of the cams.

A first follower raise relay 110 and a first follower lower relay 111 have their coils connected to the lines 87 by way of contacts 102 and 100 respectively in series with contacts 105, contacts 96 and 103 respectively in series with contacts 106, or contacts 99 and 97 respectively in series with contacts 107. Similarly, a second follower raise relay 112 and a second follower lower relay 113 have coils connected to lines 87 by way of contacts 94 and 93 respectively in series with contacts 98, contacts 90 and 95 respectively in series with contacts 101, or contacts 92 and 91 respectively in series with contacts 104.

The raise winding 33 of motor 30 is connected to a line 87 by way of normally open contacts 114 of second follower raise relay 112, and normally open contacts 115 of master raise relay 85. The lower winding 36 of motor 30 is connected to lines 87 by way of normally open contacts 116 of second follower lower relay 113 and normally open contacts 117 of master lower relay 86. The raise winding 34 of motor 31 is connected to the line 87 by way of normally open contacts 118 of master raise relay 85 in series with the parallel combination of normally open

contacts 119 of first follower raise relay 110 and normally open contacts 120 of second follower lower relay 113. The lower winding 37 of motor 31 is connected to the lines 87 by way of normally open contacts 121 of master lower relay 86 in series with the parallel combination of normally open contacts 122 of first follower lower relay 111 and normally open contacts 123 of second follower raise relay 112. The raise winding 35 of motor 32 is connected to the lines 87 by way of normally closed contacts 124 of first follower raise relay 110, normally open contacts 125 of master raise relay 85, normally closed contacts 126 of second follower raise relay 112 and normally closed contacts 127 of second follower lower raise relay 113. The lower winding 38 of motor 32 is connected to the lines 87 by way of normally closed contacts 128 of first follower lower relay 111, normally open contacts 129 of master lower relay 86, normally closed contacts 126 of second follower raise relay 112, and normally closed contacts 127 of second follower lower relay 113.

The system of Fig. 1 may be better understood from the following description of a typical operating cycle. Assuming as an initial condition that the transformers are in step and that the contacts of cams 50, 60, and 70 are closed as illustrated, if the system voltage lowers sufficiently to close the raise contacts 88 of the voltage regulating relay 21, the raise winding 35 of motor 32 will be energized by way of normally closed contacts 124 of the first follower raise relay, normally closed contacts 126 of the second follower lower relay, and the contacts 125 of the master raise relay 85. This results in a tap change in the raise direction on master transformer 12. In this tap position of master transformer 12 the cam contacts 106 will be closed. Since the first follower transformer 11 remains in its initial tap position, the contacts cam 96 also will be closed and if the voltage raising signal persists, first follower raise relay 110 will be energized by way of cam contacts 96 and 106. This results in the opening of relay contacts 124 to prevent further operation of the motor 32 of the master transformer, and closing of the relay contacts 119 to energize the raise winding 34 to make a tap change in the raise direction on motor 31 of the first follower transformer. If at this time a voltage lowering signal is received by the circuit, and master raise relay contacts 118 and 124 were opened to prevent further operation of the motors 32 and 31 respectively in the raise direction, second follower raise relay 112 will be energized by way of cam contacts 90 and 101, the lower motor circuit of motor 32 will be prevented from operation by means of the opening of contacts 126 of relay 112, and the lower winding 37 of motor 31 will be energized by way of contacts 122 of relay 112 and contacts 121 of the master lower relay 86. This results in the returning of the transformer 11 to its initial tap position. If the lowering signal still persists the lower winding 38 of motor 32 will be energized by way of normally closed relay contacts 128, 126 and 127 and master lower relay contacts 129 since relay 112 has been de-energized by virtue of the opening of contacts 101. The motor 31 of first follower transformer 11 is prevented from making a tap change in the lowering direction since the contacts 122 of relay 112 have been opened. If, however, the raise signal persists at the time when both of the transformers 11 and 12 have made one tap change, the relay 112 will be energized by way of cam contacts 90 and 101, the raise windings 34 and 35 will be de-energized since the contacts 119, 120 and 124 are opened, and the raise winding 33 of motor 30 will be energized by way of contacts 114 of relay 112 and contacts 115 of the master raise relay 85. At this time the contacts of cams 51, 61 and 71 are closed and further voltage raising signals to the circuit will result in repetition of the previously described cycle, with the first tap change being made on master transformer 12.

If at the time when the contacts of cams 51, 61 and 71

are closed a voltage lowering signal is received, the first tap change to the lowering direction will be made on master transformer 12 since contact 116 is opened to prevent lowering of the voltage of transformer 10 and contacts 122 and 123 are opened to prevent lowering of the voltage of the transformer 11. Thus the circuit of Fig. 1 is arranged so that when all of the tap changing transformers are of the same respective tap, that is, they are in step, the first tap change in either direction will be made on the master transformer 12, the second tap change of the same direction will be made by the first follower transformer 11, and the third tap change in the same direction will be made on the second follower transformer 10. If, however, a stable condition is attained in the system when the master transformer is one step above or below the tap positions of the other two transformers the first tap change to lower or raise respectively the system voltage will be made on the master transformer also. If, as a third condition, a stable system voltage is attained when the master and first follower transformers are one tap change above or below a tap position of the second follower transformer, the first tap change to lower or raise respectively the system voltage will be made on the first follower transformer, and the second tap change to lower or raise the system voltage will be made on the master transformer. In this system the transformers are never more than one tap change apart, and when the voltage of each transformer is variable in increments of V volts, the system voltage will be variable in increments of substantially V/N volts, where N is the number of parallel connected transformers. If, however, some condition exists which results in the energizing of any other tap changing motors to tend to create a condition wherein the transformers are more than one tap change apart, the previously described contact combination of the contacts of cams 53 to 56, 63 to 66 and 73 to 76 will prevent such operation.

The action of the cam contacts 90—107 may be summarized as follows. If the first follower transformer is one step above the master transformer, the lower relay 111 of the first follower transformer will be automatically energized, and if the first follower is one step below the master transformer the raise relay 110 of the first follower transformer will be automatically energized. Similarly, if the second follower transformer is one step above the first follower transformer, the lower relay 113 of the second follower transformer will be automatically energized, and if the second follower transformer is one step below the first follower transformer, the raise relay 112 of the second follower transformer will be automatically energized.

The action of the relays 85, 86, 110, 111, 112 and 133 may be summarized as follows.

In order for any of the motors to be energized to operate in a voltage raising or voltage lowering direction, a voltage raising or lowering signal respectively must be received by energization of the master raise relay 85 or the master lower relay 86 respectively.

If the first follower transformer is one step below the master transformer, only the raise relay 110 and one of the master relays will be energized. Upon initiation of a raise signal, the master transformer will be prevented from making a tap change since the normally closed contacts 124 of relay 110 are open, the second follower transformer will be prevented from making a tap change since the contacts 114 of raise relay 112 are open because the first and second follower transformers are in step, and a tap change in the raise direction may be made on the first follower transformer. If a lower signal is initiated, only the master transformer will be free to make a tap change, since the contacts 116 of relay 113, contacts 122 of relay 111, and contacts 123 of relay 112 are open.

If the first follower transformer is one step above the master transformer, only the lower relay 111 and one of the master relays will be energized. Upon initiation

of a lower signal, the master transformer will be prevented from making a tap change since the normally closed contacts 128 of relay 111 are open, the second follower transformer will be prevented from making a tap change since the first and second follower transformers are in step and the contacts 116 of relay 113 are open, and a tap change in the lowering direction may be made on the first follower transformer. If a raise signal is initiated, only the master transformer will be free to make a tap change, since the contacts 114 of relay 112, contacts 119 of relay 110, and contacts 120 of relay 113 are open.

If the second follower transformer is one step below the first follower transformer, the first follower transformer will be in step with the master transformer, and only the raise relay 112 and one of the master relays will be energized. In this event, the normally closed contacts 126 of relay 112 prevent any tap change on the master transformer. If a raise signal is initiated, the first follower transformer is prevented from making a tap change since the contacts 119 of relay 110 and contacts 120 of relay 113 are open, and a tap change may be made on the second follower transformer in the raise direction since the contacts 114 of relay 112 are closed. If a voltage lower signal is initiated, a tap change may be made on the first follower transformer since the contacts 123 of relay 112 are closed, and no tap change may be made on the second follower transformer since the contacts 116 of relay 113 are open.

If the second follower transformer is one step above the first follower transformer, the first follower transformer and the master transformer will be in step, and only the lower relay 113 and one of the master relays will be closed. The normally closed contacts 127 of relay 113 will be open, preventing any tap change on the master transformer. If a voltage lower signal is initiated, the open contacts 122 of relay 111 and open contacts 122 of relay 112 prevent tap changes on the first follower transformer, and the closed contacts 116 of relay 113 permit tap changes in the voltage lowering direction on the second follower transformer. If a voltage raise signal is initiated, a tap change may be made on the first follower transformer since the contacts 120 of relay 113 are closed, and no tap change may be made on the second follower transformer since the contacts 114 of relay 112 are open.

In the modification of my invention illustrated in Fig. 2, therein is shown a load tap changing transformer system comprising three parallel connected power circuits 140, 140' and 140''. Since these circuits are substantially identical, in order to reduce confusion the same reference numerals will be used to denote similar elements in the three circuits, the elements of circuit 140' and 140'' being distinguished by having prime marks associated therewith. Accordingly, when the circuits are identical, the detailed description will refer to only one of the circuits.

The three circuits are supplied by common alternating current supply lines 141 across which are connected the primary windings of load tap changing transformers 142, 142' and 142''. The two circuits also have a common load 143 which is connected across the tapped secondary windings of the load tap changing transformer in parallel by leads 144, 144', 144'', 145, 145', 145''. The leads 145, 145' and 145'' are connected to the tapped end of the respective load tap changing transformers, and the taps are changed by means of tap changing motors 146, 146' and 146'' respectively.

A potential proportional to the output voltage of the load tap changing transformer 142 is provided by means of a potential transformer 147 which is connected across the leads 144 and 145. The secondary winding of the potential transformer is connected in series with the coils 148 of voltage regulating relay 149 and also winding 150 and variable resistor 151 of a line drop compensator 152. Due to the operation of the voltage regulating relay 149, a change in output voltage of the transformer

142 from a predetermined value causes one of the contacts 153 and 154 of the voltage regulating relay 149 to close and actuate the motor 146 to make a tap change on the tap changing transformer 142 for correcting the system voltage of the lines 143.

In order to compensate for line voltage drop and thus provide a constant load voltage, a current transformer 156, is coupled to the lead 145 and providing a current proportional to the secondary winding current of the load tap changing transformer 142, is connected across a winding 157 and a portion of the resistance 151 of the line drop compensator 152. Since it is desirable to allow only a current proportional to the load current component of the transformer 142 to flow through the line drop compensator winding 157, a load current transformer 158 is connected in series with the winding 157, and the secondary winding of transformer 158 is connected in series with the secondary windings of the transformer 158' and 158''. This arrangement presents a high impedance for the flow of the circulating current component of the load tap changing transformer current, but a low impedance to the flow of the load current component. This effect is due to reflection of circulating current in the secondary winding of the load current transformers, the reflected currents being in such a direction as to oppose the flow of circulating current. If means were not provided for removing the circulating current from this circuit, erroneous tap changes would remain, since an increase in load current necessitates an increase in the output potential of the load tap changing transformer in order to maintain a constant load voltage, whereas an increase in circulating currents would normally be corrected by decreasing the secondary voltage of the load tap changing transformer if such circulating current is caused by an excessive secondary voltage of the load tap changing transformer.

When one or more parallel load tap changing transformers are removed from service, the remaining transformers must carry the full load. This results in an increase in the load current carried by each transformer, and unless means are provided for compensating for this condition, the additional current of the line drop compensator will cause an erroneous tap change to be made. In one method for removing this difficulty, a compensating current transformer 159 is placed in series with the load current transformer and the secondary windings of the circulating current transformers 159, 159' and 159'' are connected in series. A connection is also made between the junctions of the primary windings of transformers 158 and 159, 158' and 159', and 158'' and 159''. This arrangement forces the additional units of load current component to be bypassed and not flow through the line drop compensator.

The circulating current component flowing from the current transformer 156 flows through the third winding 160 of the line drop compensator, and this third winding 160 is interconnected with the similar windings 160' and 160'' of the circuits 140' and 140'' in such a manner that the tap changing controls always tend to reduce circulating currents.

The previously described circuit is well known, and is similar to the circuit described in U. S. Patent No. 2,322,249 which issued on application of S. Minneci and is assigned to the present assignee and also in U. S. Patent No. 2,323,716 which issued on an application of T. C. Lennox and is also assigned to the present assignee. In the past when circuits of this type have been employed, the voltage regulating relays associated with each load tap changing transformer have been set to maintain the same system voltage. In the preferred form of this modification of my invention, however, the voltage regulating relays are set to maintain the same band width, but they are each set to maintain a different voltage level. As a further distinction the third windings 160, 160' and 160'' of the load drop compensator 151,

151' and 151'' respectively are made variable for reasons that will be disclosed in more detail in the following paragraphs.

As a typical example of the operation of the circuit of Fig. 2 in accordance with my invention, assume that each tap of the load tap changing transformers 142, 142' and 142'' corresponds to a 1¼% voltage step for the respective transformer, or in other words that a tap change on one of the transformers causes a variation in the system voltage of ⅜%, if the transformers are identical or approximately ⅜% if the transformers have different impedances and a tap change on all of the load tap changing transformers in the same direction causes a variation in the system voltage of 1¼%. If it is desired to hold the voltage level at the voltage regulating relay of 120 plus or minus 0.5 volt, then the voltage regulating relay 149 would be set to close lower contacts at 121.5 volts and its voltage raising contacts at 119.5 volts. In this case a tap change on one transformer changes the system voltage by 0.5 volt. Voltage regulating relay 149' would be set to close its voltage lowering contacts at 121 volts and its voltage raising contacts at 119 volts, and voltage regulating relay 149'' would be set to close its voltage lowering contacts at 120.5 volts and its voltage raising contacts at 118.5 volts. With these settings of the voltage regulating relays there is an overall effective voltage band width of one volt at the voltage regulating relays. This one volt band width would be determined by the 119.5 volts required to close the voltage raising contacts of relay 149 and the 120.5 volts required to close the voltage lowering contacts of relay 149''. The third windings 160, 160' and 160'' of the line drop compensators are used for circulating current compensation and must be provided with an adjustment so as to allow "one step apart" operation. The reasons for this adjustment may be seen in the following paragraph.

If the voltage level at the voltage regulating relays drops to 119.5 volts, the voltage raising contacts of relay 149 will close and actuate the tap changing motor 146 to make one tap change in the voltage raising direction on load tap changing transformer 142. This results in the raising of the voltage level of the voltage regulating relays to 120 volts. Since the transformer 142 is now one tap above the other two transformers 142' and 142'', circulating current flows between the load tap changing transformers, and due to the action of the third windings of the load drop compensators, a compensating voltage will also be introduced in the voltage regulating relay coil circuits. Under the above conditions, the third windings 160, 160' and 160'' of the line drop compensators should be set so that the circulating current compensation of coil 160 is one volt, the circulating current compensation of coil 160' is 0.5 volt and the circulating current compensation of coil 160'' is 0.5 volt. This setting of the third winding is made so that current in each of the third windings 160, 160' and 160'' has the same effect on the respective voltage regulating relay coil circuits, since the current flowing through winding 160 is the sum of the current flowing through winding 160' and 160'', and is in the opposite direction. In other words, the proportion between the circulating current compensation voltage and the circulating current of each transformer is the same. With this setting the voltage at the coils of the voltage regulating relays will be the system voltages (120 volts) plus or minus the circulating current compensation voltage. Thus the voltage seen by the voltage regulating relay coil 148 is 121 volts, and the voltage seen by the voltage regulating relay coils 148' and 148'' is 119.5 volts. If the system voltage now rises to 120.5 volts, the relay coil 148 will see 121.5 volts, and therefore the voltage lowering contacts of voltage regulating relay 149 will close and actuate the motor 146 to make one tap change in the lowering direction on transformer 142. If, however, the system voltage drops to 119.5 when the load tap changing transformer 142 is one step above the other two trans-

formers, the voltage regulating relay coil 148' will see a voltage of 119 volts, and therefore the voltage regulating relay 149' will actuate the motor 146' to make one tap change in the voltage raising direction on transformer 142'. This change will bring the system voltage back to 120 volts, and since the current through third winding 160'' is now the sum of the currents through third winding 160 and 160', the coil 148 will see 120.5 volts, the coil 148' will see 120.5 volts, and the coil 148'' will see 119 volts. If at this time the system voltage rises to 120.5 volts, the first tap change in the voltage lowering direction will be made on transformer 142', and the next tap change in the voltage lowering direction, if any is required, will be made on tap changing transformer 142. If at the time when transformers 142 and 142' are one step above transformer 142'', the system voltage once again drops to 119.5 volts, the voltage regulating relay 149'' will actuate the motor 146'' to make one tap change in the raising direction on transformer 142''. At this time the system voltage will once again be 120 volts, and since all of the load tap changing transformers have made one tap change in the voltage raising direction, circulating currents will cease to flow in the current windings of the load drop compensator. Thus if the first tap change is called for in the voltage raising direction the first tap change is made on transformer 142 the next on 142', and the third on 142'', provided all transformers are on the same position when the first voltage raising operation is called for. If, however, a tap change is called for in the voltage lowering direction when all of the transformers are on the same position, the first tap change in the voltage lowering direction will be made on load tap changing transformer 142, the second tap change in the voltage lowering direction will be made on transformer 142', and the third tap change in the same direction will be made on transformer 142.

The foregoing description of the operation of the circuit of Fig. 2 is applicable in the event of changes in the load voltage slower than the response time of the tap changing mechanisms. If a rapid change occurs in the load voltage, however, and the change is sufficiently large, taps may be made simultaneously on two or more of the transformers, depending upon the magnitude of the voltage change. Thus, in the event of a rapid large change in load voltage, several or all of the transformers change taps until the load voltage reaches the desired voltage level. This feature provides as fast voltage correction as possible in the event of large load voltage variations, while retaining the advantage of providing smaller increments of voltage than are obtainable when a full tap change has been made on all transformers. The circuit of Fig. 1, however, provides sequential tap changing regardless of the magnitude of the voltage change or the rapidity of the change in relation to the response time of the tap switching mechanisms.

Proper operation of the circulating current system of Fig. 2 depends on properly correlated and accurate settings of the voltage regulating relays as to voltage level and band width. It also depends on properly correlated and accurate settings of the circulating current compensation. These settings may be different for transformers of different characteristics and thus should be made under actual operating conditions when the transformers are connected in parallel. While, as has been stated previously, it is preferred that the band width held by each voltage regulating relay be the same and all of the circulating current compensators have the same effect on their respective voltage regulating relays, other settings may be made without departing from the spirit or scope of this invention. It is necessary that one of the voltage regulating relays be set to close its voltage raising contacts at the lower limit of the desired band and that another of the voltage regulating relays be set to close its voltage lowering contacts at the upper limit of the desired band. Aside from this, the band widths of the

voltage regulating relays, and the compensating current voltages of any transformer circuit do not have to be the same as the settings on the other transformer circuits, since the effect of a larger band width may be compensated for by an increased compensation voltage.

The foregoing disclosure in reference to Fig. 2 covers three units operating in parallel. This system is equally workable with any number of units, and when the voltage of each transformer is variable in increments of V volts, the load circuit voltage or system voltage will be variable in increments of V/N volts, where N is the number of parallel connected units. However, the adjustments required may be different depending upon the number of units actually in parallel. Therefore, if any of the transformer is removed from service, or if other transformers are added in parallel, adjustments would have to be made in the control circuit. The necessary changes will be apparent from the preceding disclosure.

It will be understood, of course, that, while the forms of the invention herein shown and described constitute preferred embodiments of the 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 herein disclosed, and it is aimed in the appended claims to cover all such changes 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 an electric power system, a plurality of voltage regulating means connected in parallel between an alternating power source and a load circuit, separate control means for each of said voltage regulating means for varying the load voltages of their respective voltage regulating means in increments of V volts, said control means being arranged for varying the voltage of said load circuit in increments of substantially V/N volts in response to variations in said load circuit voltage, where N is the number of parallel connected voltage regulating means.

2. In an electric power system, a plurality of voltage regulating means connected in parallel between an alternating power source and a load circuit, separate control means for each of said voltage regulating means for varying the load voltages of their respective voltage regulating means in increments of V volts, and means interconnecting said control means, said control means and interconnecting means being arranged to provide variation of the voltage of said load circuit in increments of substantially V/N volts in response to variation of said load circuit voltage, where N is the number of parallel connected voltage regulating means.

3. In an electric power system, a plurality of voltage regulating means connected in parallel between an alternating power source and a load circuit, separate control means for each of said voltage regulating means for varying the load voltages of their respective voltage regulating means in increments of V volts, and means interconnecting said control means, said control means and interconnecting means being arranged to provide variation of the voltage of said load circuit in increments of substantially V/N volts to correct said load circuit voltage, where N is the number of parallel connected voltage regulating means, and to sequentially operate said control means in response to variations of said load circuit voltage that are slower than the response time of said control means.

4. In an electrical power system, a plurality of tap changing transformers connected in parallel between an alternating source of power and a load circuit, separate control means for each of said tap changing transformers for changing the load voltage of their respective transformers in increments of V volts, and means intercon-

necting said control means, said control means and interconnecting means being arranged to provide variation of the voltage of said load circuit in increments of substantially V/N volts to correct said load circuit voltage, where N is the number of parallel connected voltage regulating means, and to sequentially operate said control means in response to variations of said load circuit voltage that are slower than the response time of said control means.

5. In an electrical power system, a plurality of voltage regulating means connected in parallel between an alternating source of power and a load circuit, separate control means for each of said voltage regulating means for changing the load voltage of the respective voltage regulating means in finite voltage steps, and means interconnecting said control means, said control means and interconnecting means being arranged to sequentially control the load voltage of said voltage regulating means in response to variations of said load circuit voltage, and to permit normal operation of said parallel connected voltage regulating means when all of said voltage regulating means have the same load voltage and when any of said voltage regulating means has a load voltage differing from the load voltage of any other said voltage regulating means by a voltage corresponding to only one said finite voltage step.

6. In an electrical power system, a plurality of tap changing transformers connected in parallel between an alternating source of power and a load circuit, separate control means for each said tap changing transformers for changing the load voltage of their respective transformers, and means interconnecting said control means, said control means and interconnecting means being arranged to sequentially control the load voltages of said transformers in response to variation of the voltage of said load circuit, and to permit normal operation of said parallel connected transformers when all of said transformers are on the same respective tap position and when any of said transformers has a tap position only one step apart from the tap position of any other of said transformers.

7. In an electrical power system, a plurality of voltage regulating means connected in parallel between an alternating source of power and a load circuit, separate control means for each of said voltage regulating means for changing the load voltage of the respective voltage regulating means in finite voltage steps, and means interconnecting said control means, said control means and interconnecting means being arranged to sequentially control the load voltage of said voltage regulating means in response to variations of the said load circuit voltage, slower than the response time of said control means, and to permit normal operation of said parallel connected voltage regulating means when all of said voltage regulating means have the same load voltage and when any of said voltage regulating means has a load voltage differing from the load voltage of any other said voltage regulating means by a voltage corresponding to only one said finite voltage step.

8. In an electrical power system, a plurality of tap changing transformers connected in parallel between an alternating source of power and a load circuit, separate control means for each said tap changing transformers for changing the load voltage of their respective transformers, and means interconnecting said control means, said control means and interconnecting means being arranged to sequentially control the load voltages of said transformers in response to variation of the voltage of said load circuit slower than the response time of said control means, and to permit normal operation of said parallel connected transformers when all of said transformers are on the same respective tap position and when any of said transformers has a tap position only one step apart from the tap position of any other of said transformers.

9. In an electrical power system, a plurality of voltage regulating means connected in parallel between an alternating power source and a load circuit, separate control means for each of said voltage regulating means, and means for sequentially energizing said control means to correct the voltage of said load circuit, said sequential energizing means preventing simultaneous energization of said control means and preventing further energization of said control means when said load voltage has been corrected regardless of whether or not all of said control means have been energized to make the same changes in output voltage of their respective voltage regulating means.

10. In an electrical power system, a plurality of voltage regulating means connected in parallel between an alternating power source and a load circuit, separate control means for each of said voltage regulating means for changing the output voltage of the respective voltage regulating means in finite steps, and means for sequentially energizing said control means to correct the voltage of said load circuit, said sequential energizing means preventing simultaneous energizing of said control means, and preventing further energization of said control means when said load voltage has been corrected regardless of whether or not the same number of steps have been made on all of said voltage regulating means.

11. In an electrical power system of the type wherein a plurality of voltage regulating means are connected in parallel between a common alternating current power source and a common load and wherein each of said voltage regulating means has separate control means for varying its respective output voltage in finite steps, means for preventing operation of more than one of said control means at a given time to correct the voltage at said common load, and means for providing sequential operation of said control means in the event that a change is required in the output voltage of more than one of said voltage regulating means in order to correct the voltage at said common load.

12. In an electrical power system of the type wherein a plurality of voltage regulating means are connected in parallel between a common alternating current source and a common load and wherein each of said voltage regulating means has a separate control means for varying its respective output voltage in finite steps, means for obtaining changes in the load voltage in smaller increments than result from all of the control means changing the output voltage at their respective voltage regulating means one step in the same direction comprising means for preventing operation of more than one of said control means at a given time to correct said load voltage, means providing sequential operation of said control means in the event that a change is required in the output voltage of more than one of said voltage regulating means in order to correct said load voltage, and means for preventing further changes on any of said control means when said load voltage has been corrected.

13. In an electrical power system, a plurality of voltage regulating means connected in parallel between a common alternating power source and a common load, each of said voltage regulating means having separate control means for varying its respective output voltage in finite steps, and means for obtaining changes in load voltage in smaller increments than result from all of said control means changing the output voltage of their respective voltage regulating means one step in the same direction, said voltage changing means comprising means for preventing operation of more than one of said control means at a given time to correct said load voltage, for providing sequential operation of said control means in the event that a change is required in the output voltage of more than one of said voltage regulating means in order to correct said load voltage, and for preventing further changes on any of said control means when said load voltage has been corrected.

14. In an electrical power system of the type wherein a plurality of tap changing transformers are connected in parallel between a common alternating current power source and a common load, and wherein each of said transformers has a separate control means for making tap changes on its respective transformer, means for providing changes in the voltage at said load in smaller increments than result from all of said control means making a tap change on their respective transformers in the same direction comprising a voltage sensitive means for detecting the necessity for tap changes to be made to correct said load voltage, separate cam means operated by each of said control means, said cam means having contacts, a raise relay and a lower relay for each of said control means, the contacts of said voltage sensitive means being connected to energize one of said raise relays and one of said lower relays, the contacts of said one raise relay and one lower relay being connected to energize said control means to make voltage raising and voltage lowering tap changes respectively, said cam contacts being connected to energize the remainder of said relays and the contacts of said remainder of relays being connected to energize said control means so that a tap change may be made on only one transformer at a given time, tap changes are made sequentially on the transformers, and that the control means are de-energized upon correction of the load voltage regardless of whether or not tap changes have been made on all of said transformers.

15. In an electrical power system of the type wherein a plurality of tap changing transformers are connected in parallel between a common alternating current power source and a common load, and wherein each of said transformers has a separate control means for making tap changes on its respective transformer, means for providing for changes in the voltage at said load in smaller increments than result from all of said control means making a tap change on their respective transformer in the same direction comprising a voltage regulating relay connected to be energized in response to variation in said load voltage, separate cam means operated by each of said control means, said cam means having contacts, a raise relay and a lower relay for each of said control means, the contacts of said voltage regulating relay being connected to energize one of said raise relays and one of said lower relays depending upon the correction needed in said load voltage, the contacts of said one raise relay and one lower relay being connected to energize said control means to raise and lower respectively the voltage of their respective transformers, said cam contacts being connected to energize the remainder of said relays and the contacts of the remainder of said relays being connected to energize said control means such that a tap change may be made on only one transformer at a given time, the control means are energized sequentially to cause tap changes to be made on the transformers in a predetermined sequence, and upon correction of the load voltage all of the control means are de-energized regardless of whether or not all of the control means have made the same number of tap changes on their respective transformers.

16. In an electrical power system of the type wherein a plurality of tap changing transformers are connected in parallel between a common alternating current power source and a common load, and wherein each of said transformers has a separate control means for making tap changes on its respective transformer, means for providing for changes in the voltage at said load in smaller increments than result from all of said control means making a tap change on their respective transformers in the same direction comprising a voltage regulating relay connected to be energized in response to variation in said load voltage, first cam means and second cam means operated by each of said control means, said cam means having contacts, a raise relay and a lower relay for each of said control means, the contacts of said voltage regu-

lating relay being connected to energize one of said raise relays and one of said lower relays depending upon the correction needed in said load voltage, the contacts of said one raise relay and said one lower relay being connected to energize said control means to raise and lower respectively the voltage of their respective transformers, said first cam contacts being connected to energize the remainder of said relays and the contacts of the remainder of said relays being connected to energize said control means such that a tap change may be made on only one transformer at a given time, the control means are energized sequentially to cause tap changes to be made on the transformers in a predetermined sequence, and upon correction of the load voltage all of said control means are de-energized regardless of whether or not all of the control means have made the same number of tap changes on their respective transformers, the contacts of said second cams being connected to prevent energization of said one raise relay and one lower relay and thereby prevent energization of said control means when any transformer is on a tap position more than one step separated from the tap position of any other transformer.

17. In an electrical power system of the type wherein a plurality of tap changing transformers are parallel connected between a common alternating current power source and a common load circuit, means for providing changes in the voltage at said load in smaller increments than results from a single tap change in the same direction being made on all of said transformers comprising separate control means for making tap changes on each of said transformers, a separate voltage regulating relay connected to energize each of said control means to make tap changes on their respective transformers in response to a variation in said load voltage from a predetermined level, and separate circulating current compensation means in series with the coil of each of said voltage regulating relays providing a voltage that is proportional to the circulating current flowing in the respective transformer, the voltage band width and voltage level setting of each of said voltage regulating relays and the proportionality between the circulating current and the circulating current compensation voltage of each transformer being such that tap changes are made on the transformers in sequence, tap changes may not be made on more than one transformer at a given time, and the transformers may be on different tap positions as an operating condition.

18. In an electrical power system of the type wherein a plurality of tap changing transformers are parallel connected between a common alternating current power source and a common load circuit, means for providing changes in the voltage at said load in smaller increments than results from a single tap change in the same direction being made on all of said transformers comprising separate control means for making tap changes on each of said transformers, a separate voltage regulating relay connected to energize each of said control means to make tap changes on their respective transformers in response to a variation in said load voltage from a predetermined level, and separate circulating current compensation means in series with the coil of each of said voltage regulating relays, each of said voltage regulating relays being set to hold the voltage of its respective transformer within a voltage band having the same band width as that held by the other transformers and including the desired voltage level of the load voltage, each of said voltage regulating relays being set to close its contacts at voltage levels different than the other voltage regulating relays, and said circulating current compensation means being set to provide a voltage in series with the coil of

the respective voltage regulating relay that bears the same proportionality to the circulating current of the respective transformer as the circulating current compensation voltage of the other voltage regulating relays hold to the circulating currents of their respective transformers.

19. In an electrical power system of the type wherein a plurality of tap changing transformers are parallel connected between a common alternating current power source and a common load circuit, means for providing changes in the voltage at said load in smaller increments than results from a single tap change in the same direction being made on all of said transformers comprising separate control means for making tap changes on each of said transformers, a separate voltage regulating relay connected to energize each of said control means to make tap changes on their respective transformers in response to a variation in said load voltage from a predetermined level, and separate circulating current compensation means providing a voltage in series with the coil of each voltage regulating relay that is proportional to the circulating current of the respective transformer, each of said voltage regulating relays being set to hold the same voltage band width on its respective transformer, said voltage band width including the voltage level desired to be held by said transformers, but each of said voltage regulating relays being set to close their contacts at voltage levels different than the other voltage regulating relays such that tap changes are made in sequence on said transformers to correct said load voltage and that tap changes are made on only sufficient number of transformers to correct said load voltage, said circulating current compensation means being set such that the proportionality between the compensation voltage in series with the coil of the voltage regulating relays and the circulating current of the respective transformer is the same for all transformers.

20. In an electrical power system of the type wherein a plurality of tap changing transformers are parallel connected between a common alternating current power source and a common load circuit and wherein it is desired to hold the voltage level at said load within a predetermined voltage band, separate control means for making tap changes on each of said transformers, a separate voltage regulating relay connected to energize each of said control means to make tap changes on their respective transformers in response to variations in said load voltage, and separate circulating current compensation means providing a voltage in series with the coil of each voltage regulating relay that is proportional to the circulating current of the respective transformer, each of said voltage regulating relays being set to hold a voltage band width wider than said predetermined band width, the voltage band widths held by said voltage regulating relays being the same, the voltages at which said voltage regulating relays close their contacts being different, one of said voltage regulating relays being set to close its voltage raising contacts at the lower limit of said predetermined band, another of said voltage regulating relays being set to close its voltage lowering contacts at the upper limit of said predetermined band, and said circulating current compensating means being set such that the proportionality between the compensation voltage in series with the coil of the voltage regulating relays and the circulating current of the respective transformer is the same for all transformers.

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