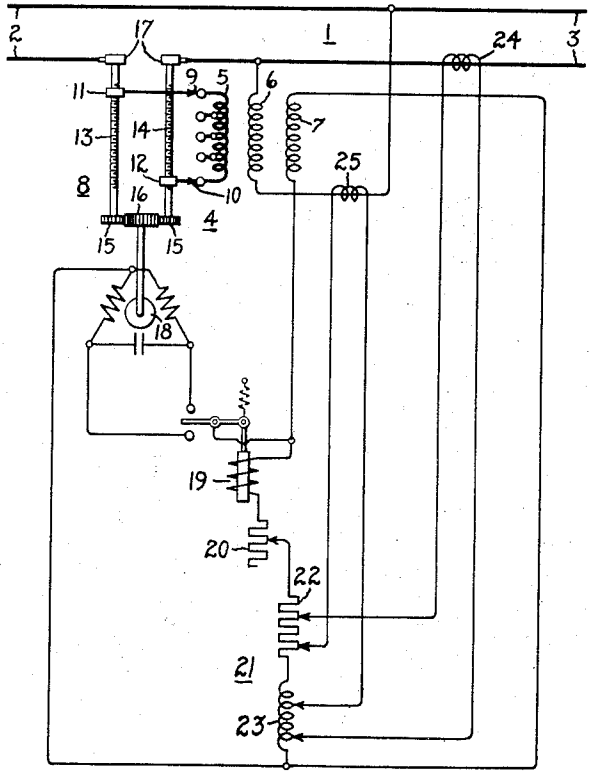
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VOLTAGE REGULATION

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VOLTAGE REGULATION

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5 Claims. (Cl. 171—119)

This invention relates to voltage regulation and more particularly to improvements in the voltage regulation of transformers.

The specific problem to which my invention is directed arises in automatic step voltage regulators. Such a regulator is usually an autotransformer which is connected in an alternating current power circuit and which is provided with automatic means for causing it to insert in the circuit variable amounts of voltage boost or buck or both in order to maintain the circuit voltage on the output or load side of the regulator constant as the load current or supply voltage or both vary. The effect of load current variations on the load voltage is similar to the effect of supply voltage variations because of the voltage drop in the impedance of the circuit. The regulator is called a step regulator because the voltage is regulated in steps by means of a tap-changing mechanism associated with the series winding of the autotransformer. The other winding is the shunt or common winding. It is called the common winding because it is common to both the primary and secondary windings. Whether it and the series winding together constitute the primary winding or the secondary winding depends upon the connections. If the series winding is connected on the supply side of the shunt winding the two constitute the primary winding and the common winding alone constitutes the secondary winding. If, however, the shunt winding is connected on the supply side of the series winding the two constitute the secondary winding and the shunt winding constitutes the primary winding. The first connection is usually used for a number of reasons. One is that the action of the regulator keeps the voltage of the shunt winding substantially constant and hence it may be made to keep the flux in the core at its optimum value.

Because the terminal voltage of the shunt winding is the same as the output or regulated voltage of the regulator it is possible to use the shunt winding as the primary winding of what may be considered as a potential transformer for supplying current to the automatic control means for the regulator. This is done by mounting an auxiliary low voltage winding on the regulator in inductive relation to the shunt winding and connecting the auxiliary winding to supply current to the voltage responsive master controller and to the operating motor of the regulator. The reason that an auxiliary supply winding on the regulator is used in place of an ordinary and separate potential transformer is that in the higher voltages such potential transformers become quite expensive and furthermore it is difficult to make them reliable because of the fact that they require a great many turns of fine wire which must be relatively heavily insulated for the high voltage.

It has been found, however, that the voltage ratio between the shunt winding of the regulator and the auxiliary winding does not remain constant with changes in load on the regulated circuit and voltage ratio of the regulating transformer itself and that consequently certain errors are introduced which prevent the regulator from maintaining constant voltage. With good design this error can be made quite small, that is to say, the maximum error can be made of the order of one per cent of the voltage of the auxiliary winding. Nevertheless, in certain cases even this error is undesirable.

In accordance with this invention I provide novel and simple means for substantially eliminating this error and for causing the effective terminal voltage of the auxiliary winding to be substantially directly proportional to the terminal voltage of the shunt winding of the regulator during all normal conditions of operation. This means is characterized by being responsive to the current in the shunt winding of the regulator because I have found that the errors to be corrected reverse when the regulator changes from boosting operation to bucking operation and as the current in the shunt winding also reverses when the regulator changes from boosting operation to bucking operation the proper direction of the correction can always be obtained.

An object of the invention is to provide a new and improved transformer system.

Another object of the invention is to provide novel and simple means for correcting for ratio errors in transformers.

A further object of the invention is to provide an improved compensated built-in control and supply circuit for automatic transformer-type voltage regulators.

An additional object of the invention is to provide an improved automatic step voltage regulator.

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

In the single figure of the accompanying drawing, which illustrates diagrammatically an embodiment of the invention, there is shown an

alternating current power circuit 1 through which power will be assumed to flow from its source or supply end 2 to its load end 3. Connected in this circuit is an automatic step voltage regulator 4 consisting of a tapped series winding 5, a high voltage shunt or common winding 6 and a low voltage auxiliary supply winding 7. These three windings are usually wound on a suitable magnetic core in the order opposite to their being mentioned above, that is to say, the auxiliary winding 7 is first placed on the core and then the common winding is placed on the core over the auxiliary winding and finally the tapped series winding is placed over the common winding. In this way the multiple taps for the series winding may most readily be brought out of the transformer and at the same time the coupling between the shunt and auxiliary windings is made relatively close while the coupling between the series and auxiliary windings is made relatively loose.

Variable portions of the series winding may be connected in the circuit 1 with either polarity so as to secure both voltage boosting and voltage bucking action. This is done by means of any suitable tap-changing means, such as the means shown schematically at 8. This consists of a pair of movable contacts 9 and 10 carried by traveling nuts 11 and 12 respectively into which are threaded screws 13 and 14 respectively. These screws carry at their lower ends pinion gears 15 which are engaged by a common driving gear 16. The upper ends of the screws 13 and 14 carry suitable means 17 for making electrical connection to the conductors of the circuit. The two screws and their associated parts are not both in the plane of the drawing so that the contacts 9 and 10 can pass each other and they are so threaded that the traveling nuts move in opposite directions as the driving gear 16 is rotated. In this manner sections of the series winding may be cut out of circuit in steps until both movable contacts 9 and 10 are in engagement with the center tap of the winding. In this position the regulator is in its neutral condition and is neither bucking nor boosting. If the gear 16 continues to rotate, the contacts 9 and 10 pass each other, thus reversing the polarity of the winding 5 and therefore reversing the direction of the regulating voltage.

It should be understood that there are many other forms of tap-changing mechanisms and that in practice suitable and well-known means is provided for preventing interruption of the main circuit during a tap-changing operation and for insuring that the tap-changing operation takes place relatively quickly.

In the illustrated form of tap-changing mechanism the gear 16 should be made of insulating material so as to prevent short circuiting the series winding.

The gear 16 is driven by a reversible motor 18 whose direction of operation is controlled by a voltage sensitive device 19, such as a contact-making voltmeter. The operating coil of the voltmeter is connected across the auxiliary winding 7 through a suitable ballast impedance 20 and a line drop compensator 21. The motor 18 is also connected across the winding 7 under the control of raise and lower contacts on the voltmeter 19.

The line drop compensator is of the resistance and reactance type consisting of a resistance element 22 and a reactance element 23, through adjustable portions of each of which a current proportional to the load current in the circuit is circulated by means of a current transformer 24.

For correcting for ratio errors in the voltage of winding 7 there is provided an additional current transformer 25 connected to circulate a corrective current through predetermined amounts of both the resistance and the reactance elements of the line drop compensator.

The operation of the illustrated embodiment of the invention is as follows. The voltage drops in the resistance and reactance elements of the line drop compensator caused by the current from the current transformer 24 lower the voltage applied to the primary relay 19 in proportion to the voltage drop in the line 1 between the regulator and the load center or any other predetermined point on the load side of the circuit. Consequently, the primary relay will not be satisfied until the output voltage of the regulator is sufficiently above the desired normal voltage to neutralize or compensate for the drop in the line. In this manner the regulator can be made to hold constant voltage at any desired point on the load side of the regulator. If the voltage departs in either direction from the desired value the relay 19 will respond by closing one or the other of its sets of contacts whereby the motor 18 will drive the tap-changing mechanism in the proper direction to restore the voltage to normal.

One of the reasons why the voltage induced in auxiliary winding 7 is not always directly proportional to the terminal voltage of the shunt winding 6 is that there is a resistance voltage drop in the winding 6 which is proportional to and in phase with the current in the winding 6. This voltage drop subtracts from the terminal voltage of the winding 6 so that increases in the current of the winding 6 cause the voltage of the winding 7 to decrease. The current in the winding 6 is equal to the difference between the input and output currents of the regulator (neglecting the normally insignificant magnetizing current of the regulator). This difference is affected by both the value of the load and by the ratio of the regulating transformer as determined by the position of the tap-changing means. However, as the error introduced by the resistance drop in the winding 6 is proportional to and in phase with the current in this winding it is compensated for by passing the current from the current transformer 25 through the proper amount of the resistance constituting the resistance element 22 of the line drop compensator.

Another cause of error in the voltage of the auxiliary winding 7 is the reactance drop in the winding 7 caused by the leakage reactance set up by currents in the windings 5 and 6. This error is in proportion to the current in the winding 6 and is in quadrature therewith and is corrected by passing the current from the current transformer 25 through the proper amount of the reactance element 23. This latter compensation is not exact for all positions of the tap-changing mechanism due to the changing reactance of the windings with changes in the position of the tap changer. However, very close compensation can be secured by selecting an average amount of compensation corresponding to an average position of the tap-changing mechanism. The deviation from exact compensation produced by changes in reactance of the winding 5 is a very small percentage of the total error which itself is very small so that its resultant effect is practically negligible.

In certain combinations of primary voltage relay and ballast impedance, such, for example, as the form described and claimed in Patent No. 2,167,473, granted July 25, 1939 on an application of W. E. Birchard and assigned to the assignee of the present application, the losses are very low so that a very small amount of energy is required for its operation. Therefore, the energy required to correct for errors in the energization of this device will also be very small (of the order of one per cent of the energy required for operating the voltmeter) and therefore current transformer **25** can be a very simple construction consisting ordinarily of a through-type current transformer having a single turn primary which can consist of a cable lead to the winding passing through an annular core structure on which can be wound a secondary winding of the transformer. In this way the introduction of windings in the power circuits of the regulator is avoided and the advantages of a potential winding for supplying the auxiliaries and automatically controlled device is retained.

With this arrangement it will be seen that no correction is produced when the regulator is in its neutral position and this is as it should be because under that condition there is no load current flowing in the shunt winding **6** and consequently there is no ratio error between the windings **6** and **7**. It will also be seen that the invention automatically produces a reversal in the phase of the corrective or compensating voltages when the polarity of the series winding **5** is reversed. This also is necessary for proper correction because the current in the shunt winding **6** and therefore the resistance and reactance drop errors associated therewith will reverse when the current in that winding reverses.

While the invention has been described specifically in connection with a step voltage regulator it will be obvious to those skilled in the art that it is not necessarily limited to such a device and that it may also be used in connection with other forms of transformer regulators, such, for example, as an induction voltage regulator.

It will also be seen that in its broader aspects my invention is not necessarily limited to use in connection with a separate voltage regulator and that in its essentials the invention is itself a voltage regulator for a transformer, that is to say, it regulates the output voltage of a transformer whose secondary winding may be considered as the winding **7** and whose primary winding is the winding **6**. Such a transformer is in one sense a potential transformer in that the voltage of the winding **7** is intended to be a measure of the voltage of the winding **6**.

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 a transformer system, a conventional-type transformer all of whose windings link the same amount of magnetizing flux, a high voltage winding on said transformer whose terminal voltage is equal to the output voltage of the transformer and whose current is equal to the difference betwen the input and output currents of the transformer, a low voltage auxiliary winding on said transformer, a load circuit for said auxiliary winding, and means responsive to the current in said high voltage winding for maintaining a substantially constant ratio between the terminal voltage of said high voltage winding and the voltage of the load circuit for said auxiliary winding.

2. In a transformer system, a conventional-type transformer all of whose windings link the same amount of magnetizing flux, a high voltage winding on said transformer whose terminal voltage is equal to the output voltage of the transformer and whose current is equal to the difference betwen the input and output currents of the transformer, a low voltage auxiliary winding on said transformer, a load circuit for said auxiliary winding, the induced voltage of said auxiliary winding departing from direct proportionality to the terminal voltage of said high voltage winding by reason of variations in internal resistance drop and leakage reactance effects in said high voltage winding with variations in current therein, and means responsive to the current in said high voltage winding for including in the voltage of the load circuit for said auxiliary winding separate voltages which compensate for said resistance drop and leakage effect whereby the voltage of said load circuit is substantially directly proportional to the terminal voltage of said high voltage winding.

3. In combination, an alternating current power circuit having a source end, a load end and a substantial amount of series impedance, an automatic step voltage regulator for said circuit comprising an autotransformer having a common winding connected across said circuit and a tapped series winding connected in said circuit on the source side of said common winding, tap-changing means for varying both the polarity and number of effective series turns of said series winding, operating means for said tap-changing means, voltage sensitive means for controlling said operating means, an auxiliary winding on said transformer for energizing said voltage sensitive means in accordance with the regulated voltage of said regulator, and means responsive to the current in said common winding for compensating for load current produced transformation ratio errors between said auxiliary winding and the common winding of said regulator.

4. In combination, an alternating current power circuit having a source end, a load end and a substantial amount of series impedance, an automatic step voltage regulator for said circuit comprising an autotransformer having a common winding connected across said circuit and a tapped series winding connected in said circuit on the source side of said common winding, tap-changing means for varying both the polarity and number of effective series turns of said series winding, operating means for said tap-changing means, voltage sensitive means for controlling said operating means, an auxiliary winding on said transformer for energizing said voltage sensitive means in accordance with the regulated voltage of said regulator, a resistance and reactance type line drop compensator serially connected with said voltage sensitive means and said auxiliary winding, a current transformer responsive to the current in said power circuit on the load side of said regulator for energizing said line drop compensator, and a second current transformer responsive to the current in said common winding for circulating an

additional current through said compensator for correcting the voltage of said auxiliary winding for departures from direct proportionality to the terminal voltage of said common winding caused by the internal resistance drop in said common winding and the leakage effect of said common and series windings on said auxiliary winding.

5. In combination, an alternating-current circuit, an autotransformer having a shunt winding connected across said circuit and a series winding connected in said circuit, an auxiliary winding inductively coupled to said autotransformer, a load circuit for said auxiliary winding, means for effectively reversing the relative direction of the turns of said autotransformer windings, a compensating impedance connected in said load circuit, and means for circulating a current in said impedance which is proportional to the current in said shunt winding.

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