No. 829,826. PATENTED AUG. 28, 1906.

E. F. W. ALEXANDERSON.

VOLTAGE REGULATOR.

APPLICATION FILED MAR. 10, 1905.

Fig. 1.

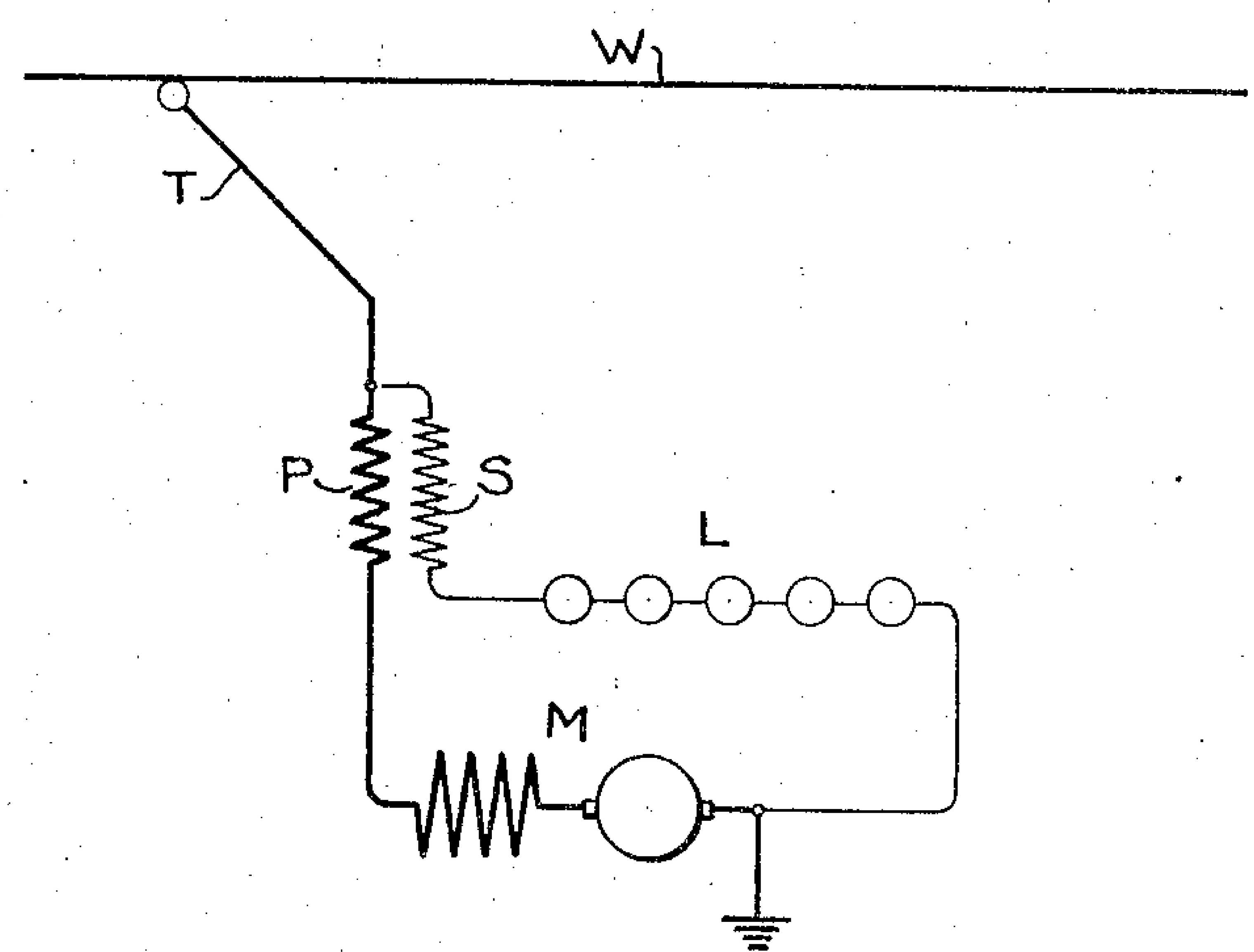


Fig. 2.

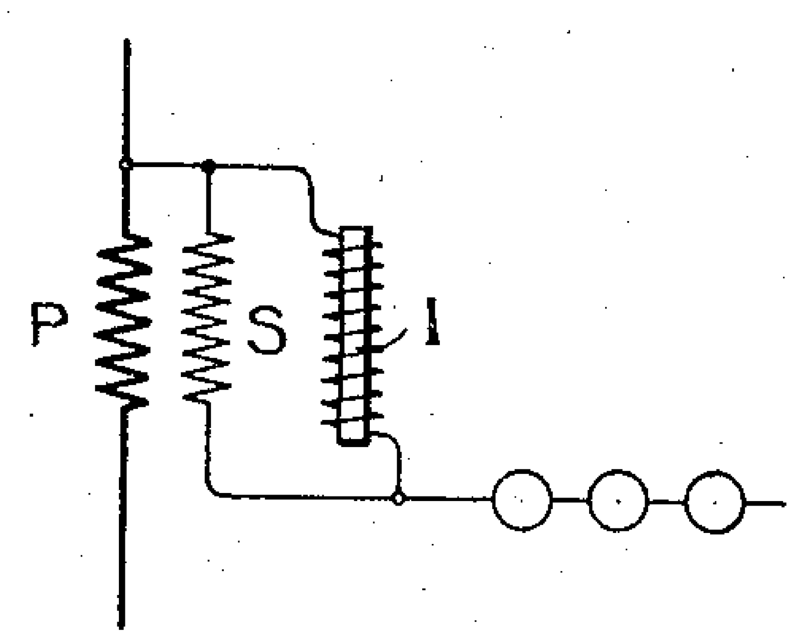


Fig. 3.

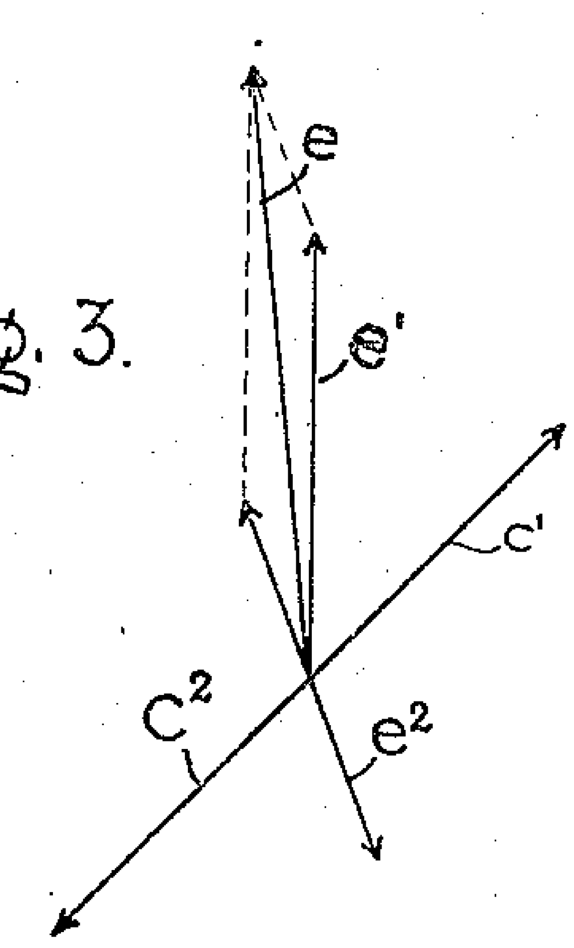


Fig. 4.

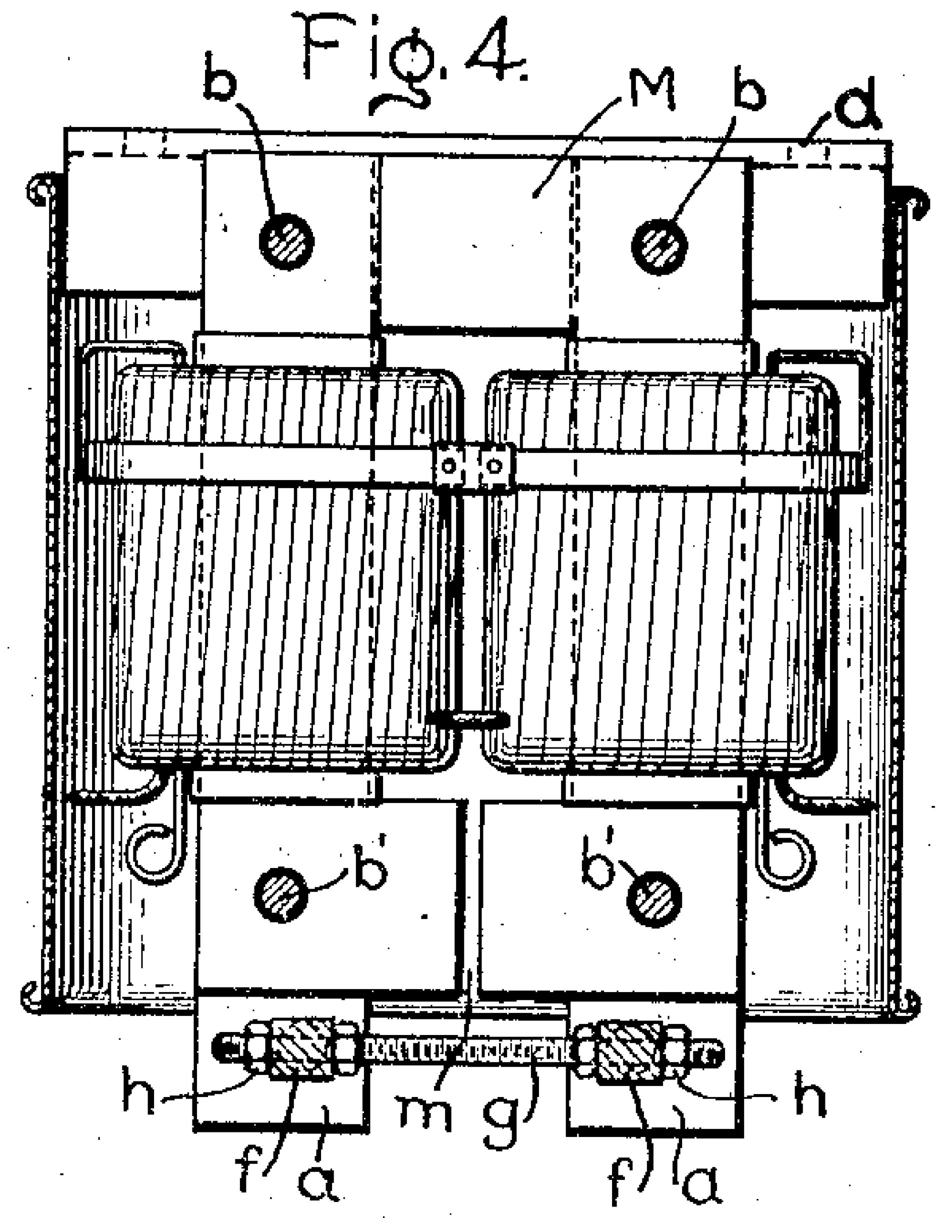
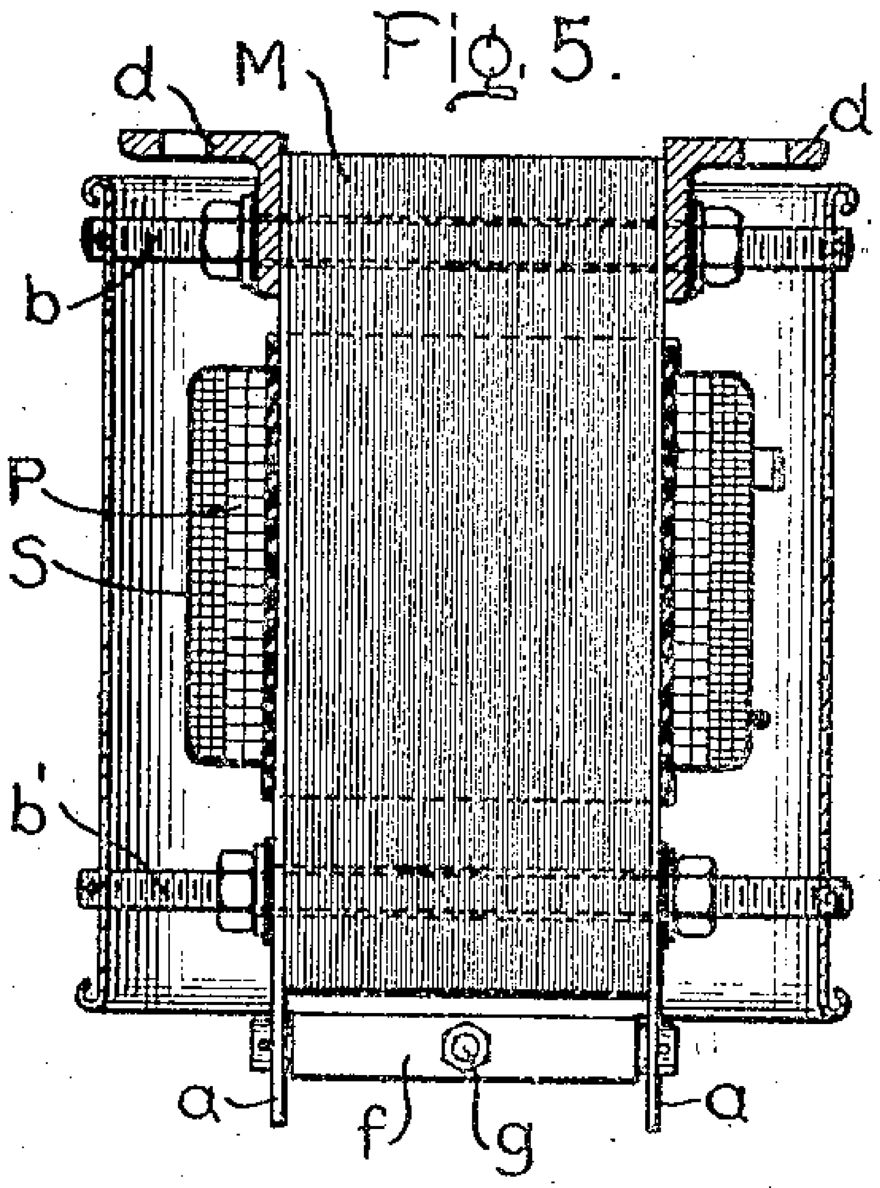


Fig. 5.



Witnesses.
Elnathan E. Briggs.
Helen Orford

Inventor:
Ernst F. W. Alexanderson
by Albert G. Davis
Att'y.

UNITED STATES PATENT OFFICE.

ERNST F. W. ALEXANDERSON, OF SCHENECTADY, NEW YORK, ASSIGNOR TO GENERAL ELECTRIC COMPANY, A CORPORATION OF NEW YORK.

VOLTAGE-REGULATOR.

No. 829,826. Specification of Letters Patent. Patented Aug. 28, 1906.

Application filed March 10, 1905. Serial No. 249,399.

To all whom it may concern:

Be it known that I, Ernst F. W. Alexanderson, a subject of the King of Sweden and Norway, residing at Schenectady, county of Schenectady, State of New York, have invented certain new and useful Improvements in Voltage-Regulators, of which the following is a specification.

My invention relates to voltage control of alternating-current circuits, and is particularly applicable to the control of the voltage impressed on a lamp-circuit on a vehicle propelled by alternating-current motors.

It is the usual practice to supply the lamps on motor-driven cars or trains from the power-circuit, connecting the lamps in parallel with the motors. It is well known that with this connection in starting or on heavy grades when the motors draw a large amount of current the voltage impressed on the lamp-circuit may be lowered, so as to decrease the brilliancy of the lamps to an objectionable extent.

The object of my invention is to provide novel means for maintaining the voltage on the lamp-circuit constant, regardless of fluctuations in the flow of current in the motor-circuit. If for this purpose a boosting transformer is used of the ordinary type in which the secondary terminal voltage on a non-inductive load, such as a lamp-circuit, is always in phase with the secondary current, the results obtained are not satisfactory if the power factor of the motor-circuit is low. This is obvious from the fact that the phase of the secondary current being determined by the phase of the primary current will be greatly out of phase with the potential in the power-circuit whenever the power factor in the motor-circuit is low, and consequently if the secondary terminal potential is in phase with the secondary current it will not be of the proper phase for most efficiently increasing the potential impressed upon the lamp-circuit. Moreover, the boosting effect will vary greatly with variation in the power factor. Furthermore, a series transformer tends to maintain the current in its secondary proportional to the primary current. This is not the effect desired; but, on the contrary, it is desired that the transformer should impress a voltage on the secondary circuit proportional to the primary current. If to gain this result the transformer secondary is shunted by a resistance, as has been suggested heretofore, not only is the secondary terminal voltage of the wrong phase, as was pointed out above, but also the resistance produces a voltage drop, which impairs the regulation of the secondary circuit if the load in that circuit is varied.

One feature of my invention consists in providing a series transformer for boosting the potential in the lamp-circuit, so arranged that the secondary terminal voltage is substantially in phase with the potential of the power-circuit, no matter how low the power factor. A transformer arranged in accordance with my invention has the further advantage, as will hereinafter appear, that the voltage drop due to the lamp-current is substantially in quadrature with the lamp-voltage and can consequently have very little effect on the regulation of the lamp-circuit when the number of lamps in circuit is varied.

Another feature of my invention consists in a novel construction of the series transformer, whereby its boosting effect may be accurately adjusted in a simple manner.

My invention will best be understood by reference to the accompanying drawings, in which—

Figure 1 shows diagrammatically the connections of the motor-circuit, lamp-circuit, and boosting-transformer on a vehicle propelled by alternating-current motors. Figs. 2 and 3 are explanatory diagrams. Fig. 4 is a side elevation of a series transformer constructed in accordance with my invention, and Fig. 5 is a side elevation of the same in cross-section.

Referring to Fig. 1, M represents a driving-motor for a vehicle adapted for operation on alternating currents. I have indicated a motor of a simple series type. For the sake of simplicity only one motor is shown and all controlling-switches are omitted. The motor M is energized from the trolley-wire W through the trolley T. In the motor-circuit is indicated the primary P of a series transformer. The secondary coil S is inserted in circuit with the lamps L, which are connected in shunt to the motor-circuit. If the power factor of the motor-circuit is low and if the series transformer is of the ordinary type in which the secondary terminal voltage is substantially in phase with the secondary current, the secondary voltage will not be of the proper phase for most efficiently boosting the voltage of the lamp-circuit. This will be evident from a consideration of Fig. 3. In this figure, e' represents the phase of the potential of the power-circuit, and c' represents the phase of the current through the motor-circuit for a given load and power factor. The current through the secondary of the series transformer will consequently be represented by the line C^2 equal and opposite to the primary current c'. If the current C^2 is greatly out of phase with the primary potential e', as shown, it is evident that if the secondary terminal electromotive force is in phase with the current C^2 the resultant of this electromotive force and the primary electromotive force e' will be much less than the sum of the two electromotive forces, so that a much greater secondary electromotive force would be required to produce a resultant of a given amount than would be the case if the secondary electromotive force were in phase with the primary electromotive force, and, furthermore, a variation in the relative phases of the two component electromotive forces will produce a considerable variation in the length of the resultant. Now if the inductance I is connected across the terminals of the secondary winding, as indicated diagrammatically in Fig. 2, the secondary terminal voltage will not be in phase with the secondary current, but the secondary current will necessarily lag behind the terminal voltage by an angle somewhat less than ninety degrees, dependent on the relative values of the inductance and the resistance of the secondary circuit. Thus with such a connection as is shown in Fig. 2 the line e^2 in Fig. 3 may represent the phase of the secondary terminal voltage. It will be seen that if the secondary winding is so connected that the secondary voltage is added to the primary voltage e' the resultant e will be very nearly equal to the sum of the voltages e^2 and e', and consequently the desired boosting effect is obtained with a boosting-transformer of the minimum size. Furthermore, since the line e^2 is substantially in line with e' a variation of the power factor in the motor-circuit over a considerable range will produce only a very slight variation in the length of the line e, so that if the transformer is properly adjusted to give the desired phase relations for the average factor of the circuit the phase relations for all load conditions in the motor-circuit will be substantially correct, and, furthermore, since the voltage drop in the inductance due to current-flow in the lamp-circuit is in quadrature with that current it could have no appreciable effect on the lamp voltage even if the load on the lamp-circuit should be varied.

It is not necessary that an external inductance should be employed for obtaining the desired phase relations. The same result can be obtained by proper design of the transformer itself. By forming the magnetic circuit with an air-gap the same effect electrically is produced as with an inductance in shunt to the secondary. A suitable construction for the transformer is shown in Figs. 4 and 5. In these figures, M represents the magnetic circuit, which is formed with an air-gap at its lower end, as indicated at *m* in Fig. 4. The magnetic circuit M is constructed of laminations, as shown in Fig. 5, which are pressed together between clamping-plates *a a* by the bolts *b b'*. The bolts *b* at the top of the transformer serve also to secure the magnetic core to suitable supporting members *d d*. These upper bolts *b b* furthermore act as pivots, on which the legs of the magnetic circuit on which the coils are supported may be adjusted toward and away from each other. For securing this adjustment the clamping-plates *a a* are extended at the lower ends of the legs, as shown in the drawings, and opposite plates are connected by rods or bars *f*. The two bars *f* are connected to each other by a screw-threaded rod *g*, which is provided with suitable nuts *h*, by means of which the pivoted legs of the magnetic core may be moved toward or away from each other, so as to adjust the length of the air-gap *m*, and locked in position. By means of this adjustment the secondary terminal voltage may be varied in amount relative to the primary current, so that the proper boosting effect may be obtained with great exactness. This adjustment varies to a small degree the relative phases of secondary current and terminal voltage; but, as has already been pointed out, if the secondary terminal voltage is of substantially the proper phase a considerable shift in phase has only a small effect upon the resultant voltage in the lamp-circuit.

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

1. In combination, an alternating-current motor-circuit having a low-power factor, a lamp-circuit in shunt thereto, and a transformer having its primary in series with the motor-circuit and its secondary in series with the lamp-circuit and adapted and arranged to produce a secondary terminal voltage substantially in phase with the impressed voltage in the motor-circuit.

2. In combination, an alternating-current motor-circuit, a lamp-circuit in shunt thereto, and a series transformer having an air-gap in its magnetic circuit and its primary and secondary windings included in said motor-circuit and in said lamp-circuit respectively.

3. In combination, an alternating-current motor-circuit, a lamp-circuit in shunt thereto, a series transformer having an air-gap in its magnetic circuit and its primary and sec-

ondary windings included in said motor-circuit and in said lamp-circuit respectively, and means for adjusting the length of said air-gap.

4. In combination, two single-phase load-circuits supplied in parallel from the same source, a series transformer having its primary and secondary windings included in series with said two circuits respectively and having a magnetic core comprising a pivoted member arranged by its movement to produce an air-gap of variable length in said core, and means for clamping said member in position.

5. In combination, two single-phase load-circuits supplied in parallel from the same source, a series transformer having its primary and secondary windings included in series with said two circuits respectively and having a magnetic core comprising two pivoted legs adjustable toward and away from each other to produce an air-gap of variable length in said core, and an adjustable locking device for determining the length of the air-gap.

6. In combination, an alternating-current motor-circuit of variable current and power factor, a lamp-circuit in shunt thereto, and a series transformer having its primary and secondary windings included in said motor-circuit and in said lamp-circuit respectively and adapted and arranged to produce a secondary terminal voltage substantially in phase with the voltage on the motor-circuit when the motors are working with an average power factor.

7. In combination, an alternating-current motor-circuit having a low-power factor, a lamp-circuit in shunt thereto, and a transformer having its primary in series with the motor-circuit and its secondary in series with the lamp-circuit and so arranged that the voltage drop in the secondary of said transformer due to flow of current in the lamp-circuit is substantially in quadrature with said current.

8. In combination, two single-phase circuits supplied in parallel from the same source, one of said circuits having a load of low-power factor, and a transformer having its primary in series with the circuit of low-power factor and its secondary in series with the other circuit and adapted and arranged to produce a secondary terminal voltage displaced from the secondary current by an angle approximately equal to the average angle of lag in the circuit of low-power factor.

9. In combination, two single-phase load-circuits supplied in parallel from the same source, and a series transformer having an air-gap in its magnetic circuit and its primary and secondary windings included in series with said two circuits respectively.

10. In combination, two single-phase load-circuits supplied in parallel from the same source, a series transformer having an air-gap in its magnetic circuit and its primary and secondary windings included in series with said two circuits respectively, and means for adjusting the length of said air-gap.

In witness whereof I have hereunto set my hand this 9th day of March, 1905.

ERNST F. W. ALEXANDERSON.

Witnesses:
BENJAMIN B. HULL,
HELEN ORFORD.