

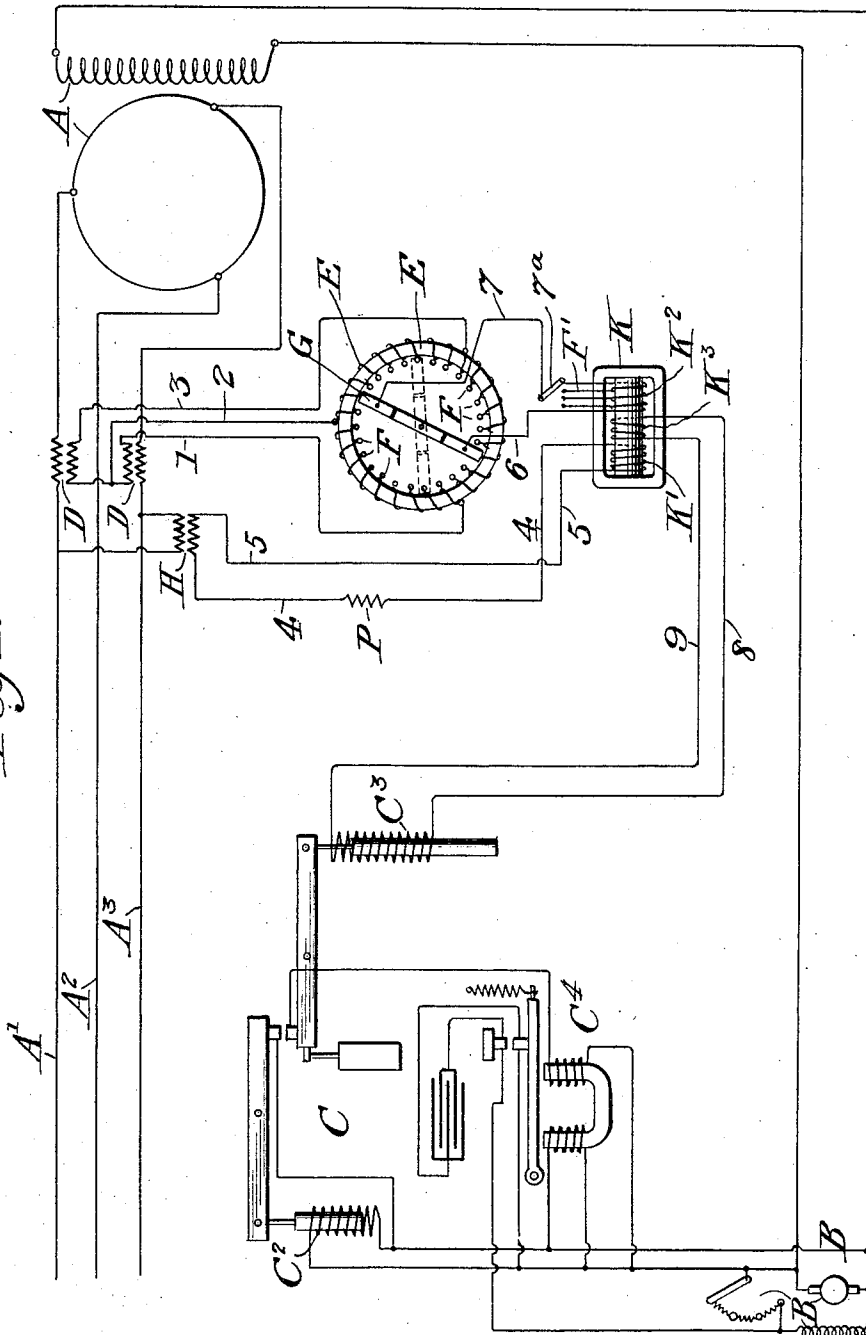
J. PEARSON.
METHOD OF LINE DROP COMPENSATION.
APPLICATION FILED JULY 22, 1910.

1,050,082.

Patented Jan. 7, 1913.

3 SHEETS—SHEET 1.

Fig. 1.

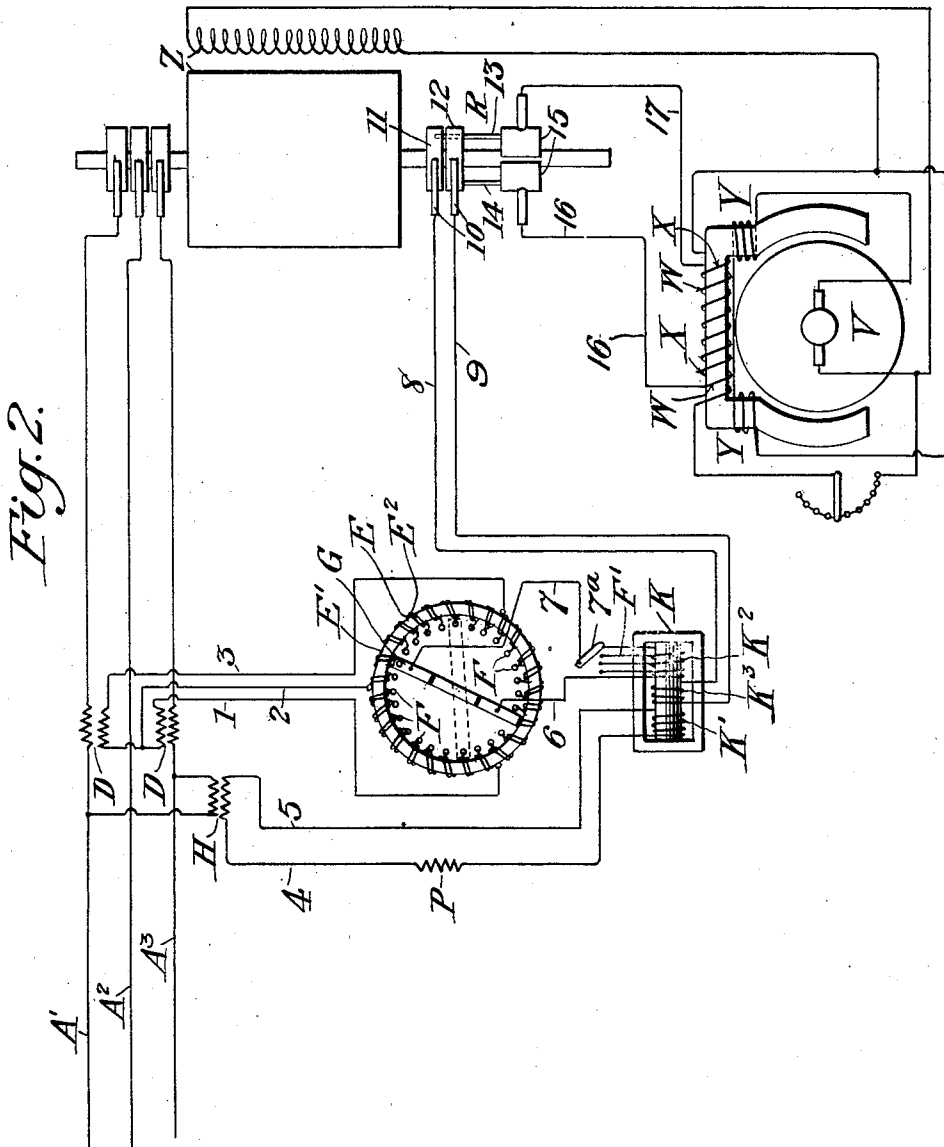


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3 SHEETS—SHEET 2.



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3 SHEETS—SHEET 3.

Fig. 3.

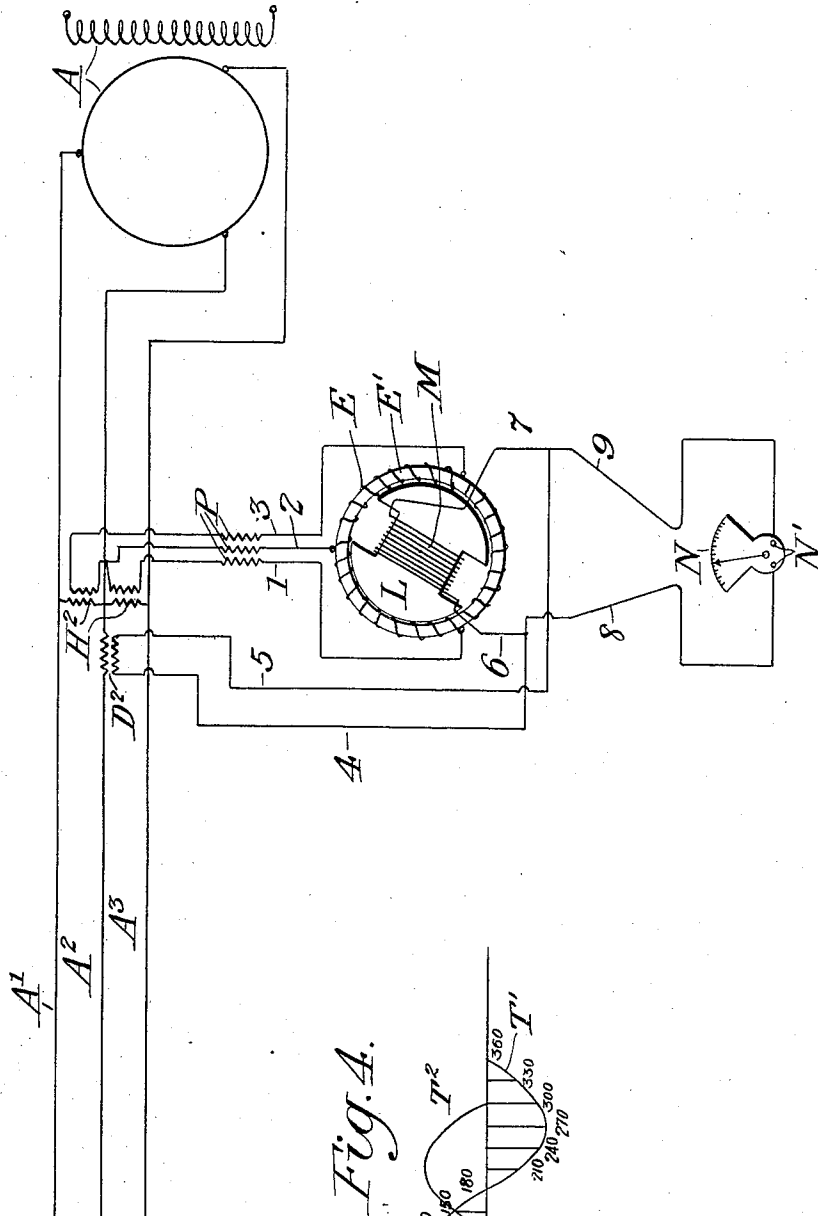
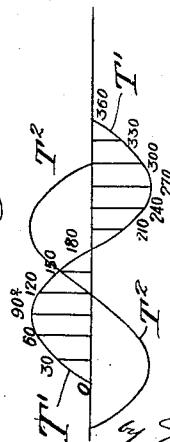


Fig. 4.



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UNITED STATES PATENT OFFICE.

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METHOD OF LINE-DROP COMPENSATION.

1,050,082.

Specification of Letters Patent.

Patented Jan. 7, 1913.

Original application filed October 10, 1907, Serial No. 396,808. Divided and this application filed July 22, 1910. Serial No. 573,218.

To all whom it may concern:

Be it known that I, JOHN PEARSON, a citizen of the United States, residing at Somerset, county of St. Croix, State of Wisconsin, have invented certain new and useful Improvements in Methods of Line-Drop Compensation; and I do hereby declare the following to be a full, clear, and exact description of the invention, such as will enable others skilled in the art to which it appertains to make and use the same.

This application which is a division of my prior application, Serial No. 396,808, filed October 10, 1907, relates to and has for its object a novel and efficient method of regulating an alternating current generator so as to maintain constancy of voltage, or as nearly so as possible, at the distributing end of a long distance transmission line; and to this end, my invention consists of the novel means for this purpose hereinafter disclosed and pointed out in the claims.

The desirability of keeping the voltage constant, or as nearly constant as possible, at the distributing end of an alternating current transmission line has long been well recognized. In practice, however, this has been found to be an extremely difficult problem. If the transmission line is supplying current for motors, especially induction motors, variations in phase difference between current and voltage, on the line, are greatly increased, as compared with some other classes of service. If, for example, the line is supplying simply an incandescent lighting system, as is common in night service, the power factor will be comparatively high; but if supplying motors, especially induction motors—as is common in day service, the power factor will be comparatively low. The self-inductance, the capacity of the line, and the ohmic drop or resistance of the line, must also be taken into consideration. Because of all these things, taken collectively, practice shows that there is a tendency for a transmission line to decrease the voltage at the distributing end, if the current lags behind the voltage, and to increase the voltage at said distributing end, if the current leads the voltage. The drop in the voltage incidental to the lag of the current and ohmic resistance of the line has been most generally considered, and is generally spoken of as line drop. So far as I know,

no successful method has ever been provided, in the prior art, for the complete compensation of these voltage variations at the distributing end of a transmission line. The generator or generators at the generating station have, it is true, had regulators for voltage, but none thereof hitherto in use have, so far as I am aware, been adequate to effect the needed compensation. For example, the well known Tirrill voltage regulator is extensively used; and this Tirrill regulator, as is well known, includes a so-called alternating current control magnet which is of solenoid form and has two coils, one for voltage and the other for current, with circuit connections from the main line, and which elements are designated to compensate for I^2R losses; or, more loosely stated, they are intended to compensate for losses due to current and resistance. The said Tirrill regulator does thus take more or less note of variations in load, but it does not take sufficient note of power factor changes. The standard Tirrill regulator will compensate, fairly well, when the power factor does not vary much; but, in cases where the power factor varies from 85 to 100 per cent., the voltage will vary several per cent. at the distributing end of a transmission line supplied through a generator controlled by a Tirrill regulator.

I am also aware of the so-called Mershon compensator; but where an inductive resistance and ohmic resistance are connected in parallel, as in the Mershon compensator, there will be a tendency to increase or decrease the voltage, whenever the frequency changes; for the reason that, when the frequency gets higher, more current will pass through the ohmic resistance and less through the inductive resistance. For this reason, the Mershon compensator cannot, in my judgment, be successfully applied to a Tirrill regulator, nor to a compound wound exciter; but might possibly be applied to a reading instrument, such as a voltmeter, wherein very little current only is needed.

My new compensating method, herein disclosed, is intended not only to consider the I^2R losses, as in the devices of the prior art, but to take full note of power factor changes. To this end, I provide means for taking off current and voltage from the transmission line and delivering the same at

a phase difference increased as compared with the phase difference on the line, so as to thereby secure a resultant which will be effective for producing the required compensation, when applied, for example, to the alternating current control magnet of the Tirrill regulator or to a third coil on a compound exciter. The said resultant, so secured, may be applied simply to a voltmeter at the generating station, to indicate the voltage at the distributing end of the line, and thereby to enable the operator to change the regulation of the generator as required to effect the needed compensation.

The accompanying drawings illustrate several applications of my invention.

In said drawings, wherein like notations refer to like parts throughout the several views; Figure 1 is a diagram view illustrating my invention as applied to the Tirrill regulator. Fig. 2 is a similar view illustrating my invention as applied to a compound exciter; Fig. 3 is a similar view illustrating a modification as applied simply to a voltmeter, and Fig. 4 is a phase diagram.

Referring to Fig. 1, A represents a three phase generator, and A^1 , A^2 , and A^3 the corresponding wires of a long distance transmission line. The field of said generator A is subject to an outside exciter B. The exciter B is subject to a voltage regulator C. This regulator C is so nearly identical with the structure of the standard Tirrill regulator that it is sufficient to note the only material difference. This difference is due to the modification made to adapt the Tirrill regulator to my compensating means, as illustrated in Fig. 1; and to this end, the so-called alternating current control magnet of the regulator C employs only a potential coil C^3 instead of having the customary pair of coils, and the resultant from my compensator is delivered to this potential coil C^3 of said regulator C. C^2 is the direct current control magnet and C^4 the relay magnet of the Tirrill regulator.

The primary feature of my compensator is what I call a phase transformer, but preferably also includes a compensating transformer. These devices, with their proper circuit connections, will now be described in detail. The compensating transformer K, as shown in Figs. 1 and 2, has a pair of coils K^1 and K^2 , one for current and the other for voltage, so connected that the current travels in opposite directions therethrough and between the two is placed a third coil K^3 which delivers the resultant over the wires 8 and 9 to said potential coil C^3 of said regulator C. As shown in Figs. 1 and 2, the coil K^1 is a potential or voltage coil, being connected across the main line by voltage transformer H, and the wires 4 and 5 leading therefrom to the said coil K^1 ; and is therefore adapted to take from the

main line a true proportion of the voltage, in step with the voltage on the main line and of a certain phase relation to the current on the main line. As shown in said Figs. 1 and 2, the other coil K^2 is a current coil connected up with the main line, through series transformers D and my phase transformer, which, as shown in Fig. 1, is made up of the parts marked E, E^1 , F and G. The part E is a coil wound on an annular laminated core E^1 and this coil E is tapped at three equi-distant points by the three wires or phase leads 1, 2 and 3 leading from said series transformers D. These wires 1, 2 and 3 deliver to said coil E current which holds a true proportion to the total main line current, on all the phases, and which is of a certain phase relation to the main line current. The parts F are a series of taps, tapping the coil E at equi-distant points, around the inner circle of the annular core E^1 ; and, across the diameter of this circle, is centrally pivoted a sectional contact lever G, the outer or end sections of which are insulated from the central section thereof and may be made to engage with any desired pair or opposite members of said taps F, by swinging said lever on its pivotal center. The said outer ends of said contact lever G have off leading wires marked, respectively, 6 and 7. The said device, composed of the said parts E, E^1 , F and G, is adapted to take from the main transmission line multi-phase current or voltage and deliver the same in a single phase over the wires 6 and 7. With the circuit connections as shown, it takes in multi-phase current and delivers the same in a single phase. The wires 6 and 7 connect with the coil K^2 or current coil of said transformer K, the wire 6 connecting directly therewith, and the wire 7 through a switch button 7^a and any selected one of a series of leads F^1 brought out from different points along the coil K^2 . The purpose of the series of leads F^1 is to vary the strength of the coil K^2 as may be required, depending on the amount of ohmic drop in the transmission line. By changing the contact lever G from one set or opposite pair of taps F to another opposite pair of said taps, the phase of the current taken off over the wires 6 and 7 and delivered to the coil K^2 , relative to the voltage delivered over the other circuit to the coil K^1 , can be changed so as to increase this phase difference relative to the phase difference on the main line, so as to get a resultant in the coil K^3 which will be effective for compensation; or which will consider effectively power factor changes on the main line. Assuming that the said contact lever G has been properly set to thus secure in the coil K^2 a single phase current of the proper phase difference relative to the current in the coil K^1 , for due consideration of the power factor changes on the main line,

and the switch button 7^a has been connected to the proper member of the leads F¹ to make the coil K² of the proper strength for due consideration of the ohmic drop of the main line;—then, thereafter, the compensation will be automatic, or, otherwise stated, the resultant coil K³ will, thereafter, deliver over the wires 8 and 9 a resultant to the potential coil C³ of the regulator C, which will be effective to secure the desired full compensation. At no load, the E. M. F. in the coils K¹ and K³ will be approximately equal, but as the load comes on, the current in coil K² begins to reduce the E. M. F. in the resultant coil K³, just as the transmission line reduces the E. M. F. at the distributing end thereof; and this will allow the core of the alternating current control magnet of the regulator C to drop, with the result that the bus bar voltage of the generator will be raised under the control of said regulator. When the loads falls off, the reverse actions, of course, take place.

In all cases, it is desirable to have current in the coil K² shifted in phase more than 180 degrees in the direction that the main current shifts when the main current leads, for example, the required shift may be 60 degrees more, in order to make the proper compensation for the power factor changes on the main line as shown in the phase diagram Fig. 4 of the drawings. In this phase diagram, the curve T¹ represents the phase of the current in the coil K¹ or the one responding to voltage, and the curve T² represents the phase of the current in the coil K² or the one responding to current, on power factor unity. By reference to this diagram, it will be seen that the phase of the current in coil K² is sixty electrical time degrees ahead of true opposition of the phase of the current in the coil K¹, and that the two are in opposition to a certain extent. This sixty degrees of difference from true opposition on power factor unity is due to the position at which the lever G of the phase transformer is set; and it is because of this increase of the said phase difference that the resultant in the coil K³ is rendered effective. Having thus shown the phase displacement on unity power factor, it can readily be seen that as the main line current lags, the current in coil K² will also lag and come more nearly in opposition to the current in the coil K¹, thereby reducing the strength of the resultant coil K³. If the current on the main line begins to lead more, then the current in coil K² will lead more, thereby throwing the current in the coils K¹ and K² into less opposition of phase, and thus increasing the strength of the resultant coil K³. These are precisely the actions required to secure the compensation desired. The question then arises how can it be known which is

the proper direction to swing the contact lever G. The answer is that the phase transformer is tested out and graduated for that purpose, for the particular line where applied. That this can be readily done, may be understood from the following statements. The field of the core E¹ is rotating. Let it be assumed that this field rotates counter clockwise; that the phase transformer is connected as shown in Fig. 1, and that the power factor of the line is, at a given instant, 100 per cent. Then swing the lever G one way or the other, until the core of the alternating current control magnet of the regulator C drops to its lowest point, and mark the position at which the said lever G stood on the core E¹. This, for example, may be the dotted line position of said lever, as shown in Fig. 1. At this, which might be called the first position for the purpose of graduation, the current in the coils K¹ and K² will be in opposite phase, inasmuch as the power factor is 100 per cent. Next, take a reading of the power factor of the system when the current lags, about 30 degrees, and shift the lever G again, one way or the other, until the alternating current magnet core of the regulator C again drops to its lowest point, and mark the then position of said lever G on the core E¹. This may be called the second graduating position. Finally, take a reading of the power factor of the system when the current leads, about 30 degrees, and then shift the lever G again, one way or the other, until the core of the alternating current control magnet again drops to its lowest point and mark the position of said lever G on the core E¹. This may be called the third position for graduating purposes. Thereafter, by referring to these three graduation marks on the core E¹, the operator will know, by the position of the contact lever G, when the current in the coil K² is in opposite phase relative to the current in coil K¹ on power factor 100 per cent.; and will further know in which direction from this primary graduation the lever G must move for lag or lead of the current in the coil K² relative to current in coil K¹.

The full line position of the lever G, as shown in Fig. 1, is the position, approximately, which I have found to be highly efficient for securing effective compensation with this identical device connected up as there shown on a transmission line of which I am in charge. This working position is about 60 degrees counter clockwise from the dotted line position of said lever; and said dotted line position is the one which said lever G would occupy, in my working system, in order to get the current in coils K¹ and K² in opposite phase, on power factor 100 per cent. The lever G being adjustable,

the same may be set for any displacement of phase required to secure complete compensation and thereby the desired constancy of voltage at the distributing end of the line. Some systems require and will stand a greater phase displacement than others.

Referring to Fig. 2, my invention is there illustrated as connected up for securing the desired compensation through the compound exciter of a three phase generator. The compensator, shown in Fig. 2, is identical with that shown in Fig. 1, with the exception that the core E^1 is now provided with two windings E and E^2 , the former being connected to the leads A^1, A^2, A^3 , as in Fig. 1, and the latter being in inductive relation to the said winding E , so that the two windings E and E^2 are related as primary and secondary respectively, and the only difference in the action is that thereby a distinct induced current is afforded for the coil K^2 instead of current taken more directly from the main line. In said Fig. 2, Z represents the generator, the field of which is subject to a compound exciter V , and this exciter V is regulated by my compensator, through the so-called rectifier R . The standard connections from such a compound exciter V and a rectifier R are well known, and it is not deemed necessary to trace the same in detail. It is deemed sufficient to note the additions for connecting in my compensator. To this end, the compound exciter has a third winding W , in addition to the old or series winding Y and the shunt winding X ; and which new winding W gets its current, through the rectifier R , from the resultant coil K^2 of my compensating transformer K . The course of the current is over the wires 8 and 9, brushes 10, slip rings 11 and 12 of the rectifier, thence through the leads 13 and 14 to the commutator 15, and thence over the wires 16 and 17 to said coil W of the exciter V . The windings X, Y and W , of said compound exciter, are all wound in the same direction on a common core; and consequently each winding is helping the other to raise or lower the voltage of the exciter; and hence, of the alternator and transmission line. With these connections, therefore, the coil W will cooperate with the coils X and Y of said compound exciter, so as to effect compensation for the voltage changes at the distributing end of the transmission line, to the same effect as the resultant from the compensator acts through the Tirrill regulator in Fig. 1, assuming that the speed of the generator Z is constant. Otherwise stated, when the coil W is added to the said compound exciter and connected up with the other parts of my compensator through the rectifier, the said compound exciter becomes a voltage regulator for the generator Z and is properly compensated as described.

Referring to Fig. 3, a modification is there illustrated wherein the connections from the main line may be said to be reversed in respect to current and voltage, as compared to the form of the compensator shown in Figs. 1 and 2; and the phase transformer proper is modified, as required for this change or reversal in the circuit connections. Otherwise stated, the phase transformer in Fig. 3 is now in the circuit which responds to voltage, instead of being in the circuit which responds to current, as shown in the other views. Respecting details, it may first be noted that instead of a simple contact lever G , a wound pivoted core L is substituted for cooperation with the annular core E and the coil E^1 thereon. The core L , with its coil M , may be swung so as to span any desired diameter of the core E , just as could the contact lever G in the other view. The wires 1, 2 and 3 are, in Fig. 3 connected across the main line to voltage transformers H^2 instead of to series transformers, as in the other views; and the wires 4 and 5 are now connected with the main line through a series transformer D^2 , instead of across the main line through voltage transformers, as in Figs. 1 and 2. With this construction, the winding M on the pivoted core L delivers current over the wires 6 and 7 to points of junction with the wires 4 and 5, and thence the resultant is taken over the wires 8 and 9 to the taps N^1 of the voltmeter N . It will thus be seen that the voltmeter N , the secondary of the transformer D^2 and the coil M are in parallel, so that the effective voltage passing through the voltmeter N will be the resultant of the voltages from the transformer D^2 and the coil M . In this modification, a true proportion of the voltage will be taken from all the phase leads of the transmission line, and be transformed and delivered by the phase transformer in a single phase voltage over the wires 6 and 7, and the phase difference of this voltage relative to the current supplied over the wires 4 and 5 will be increased, relative to the phase difference of the main line, and may be varied, by shifting the position of said core L , so as to get a resultant from said two circuits which will be effective, when delivered through the wires 8 and 9, either for the purposes of compensation or for indicating the voltage at the distributing end of the transmission line. If connected to the voltmeter, as shown, the reading is given; but the wires 8 and 9 could be run to the potential coil C^3 of the Tirrill regulator, as shown in Fig. 1, and be used for regulating purposes.

It will be understood, of course, that it is a great advantage to know, at the generating station, what the voltage is at the distributing station. The device connected up as shown in Fig. 3 will give this reading.

The forms shown in Figs. 1 and 2 would also do the like, if the reading instrument was connected to take the resultant from the coil K³ as there shown.

5 It should be further noted, that the compensating transformer K, shown in Figs. 1 and 2, could be dispensed with, and the two pairs of wires (4 and 5) and (6 and 7) be applied, respectively, to the pair of oppositely wound coils of the alternating current control magnet of the standard Tirrill regulator; and the resultant, from the said two circuits from the main line, would then take effect on the core of that magnet and give the compensation required. It is an advantage, however, to have the compensating transformer K; because, otherwise the coils of the alternating current control magnet of the Tirrill regulator would have to be made very large, on account of the phase difference employed in my compensating system.

It should, perhaps, be noted that, having regard to the two circuits from the main or transmission line, proper resistance P must be located in the circuit which takes voltage from the main line.

What I claim is:—

1. The method of regulating the voltage of a multi-phase alternating current circuit which consists in deriving two circuits from the transmission line, one a voltage circuit and the other a current circuit, transforming the current in one of said circuits to produce a phase difference increased as compared with the phase difference on the line, inductively combining the effects of the currents of said circuits to produce a resultant regulating current.

2. The method of regulating the voltage of a multi-phase current circuit which consists in deriving two circuits from the transmission line, one a voltage circuit and the other a current circuit, transforming the current in one of said circuits to produce a phase difference increased as compared with the phase difference on the line, and combining the effects of the currents of said circuits to produce a resultant regulating current.

3. The method of regulating the voltage of a multiphase alternating current circuit which consists in deriving two circuits from the transmission line, one a voltage circuit and the other a current circuit, transforming the current in one of said circuits to produce a phase difference increased as compared with the phase difference on the line, combining the effects of the currents of said circuits to produce a resultant magnetism and thereafter utilizing the resultant magnetism to produce a regulating current, and regulating

the magnetic effect of one of said currents on the other to fix the value of said resultant magnetism with respect to the power factor of the transmission line.

4. The method of regulating the voltage of a multiphase alternating current circuit which consists in deriving two circuits from the transmission line, one a voltage circuit and the other a current circuit, changing the phase difference of the current in said current circuit to cause the current of said current circuit to lead or lag the current of the main circuit according as the current of the main circuit is leading or lagging, combining the effects of the current of said voltage circuit and the changed current of the current circuit to produce a resultant current, and thereafter utilizing the resultant to operate a regulating device.

5. The method of deriving operating current from a multi-phase transmission line to operate a regulating device which consists in deriving two circuits from said transmission line, one a multi-phase current circuit and the other a single phase voltage circuit, transforming the current of the multi-phase current circuit to a single phase current of a magnified phase difference as compared with that of the current of the main line, and thereafter combining the effects of the current of the voltage circuit and the transformed current of the current circuit to produce a resultant current in a third circuit associated with the regulating device.

6. The method of deriving operating current from a multi-phase transmission line to operate a regulating device which consists in deriving two circuits from said transmission line, one a multi-phase current circuit and the other a single phase voltage circuit, transforming the current of the multi-phase current circuit to a single phase current of a magnified phase difference as compared with that of the current of the main line, and thereafter combining the effects of the current of the voltage circuit and the transformed current of the current circuit to produce a resultant current in a third circuit associated with the regulating device, and regulating the current in one of said circuits to fix the value of said resultant current with respect to the power factor of the transmission line.

In testimony whereof I affix my signature, in presence of two witnesses.

JOHN PEARSON.

Witnesses:

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ROSE C. LA GRANDEUR.