March 25, 1930. F. WUNSCH 1,751,539

FREQUENCY AND SPEED CONTROL

Original Filed March 27, 1925 2 Sheets-Sheet 1

Fig. 1.

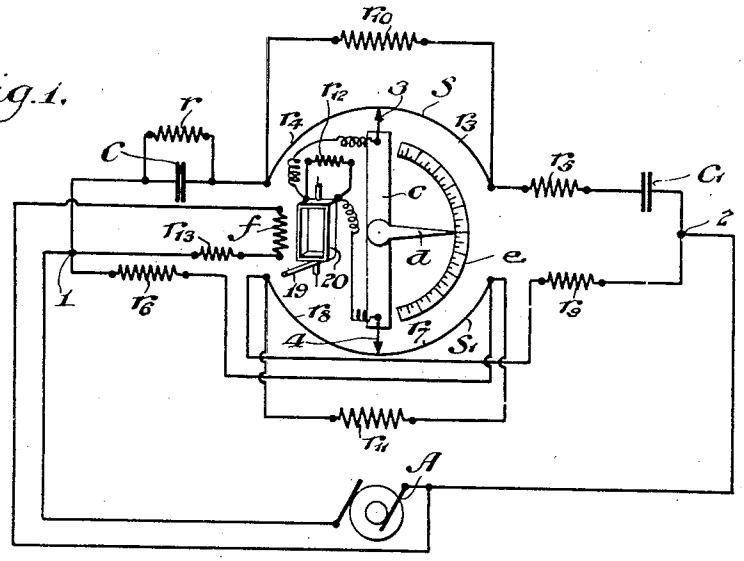
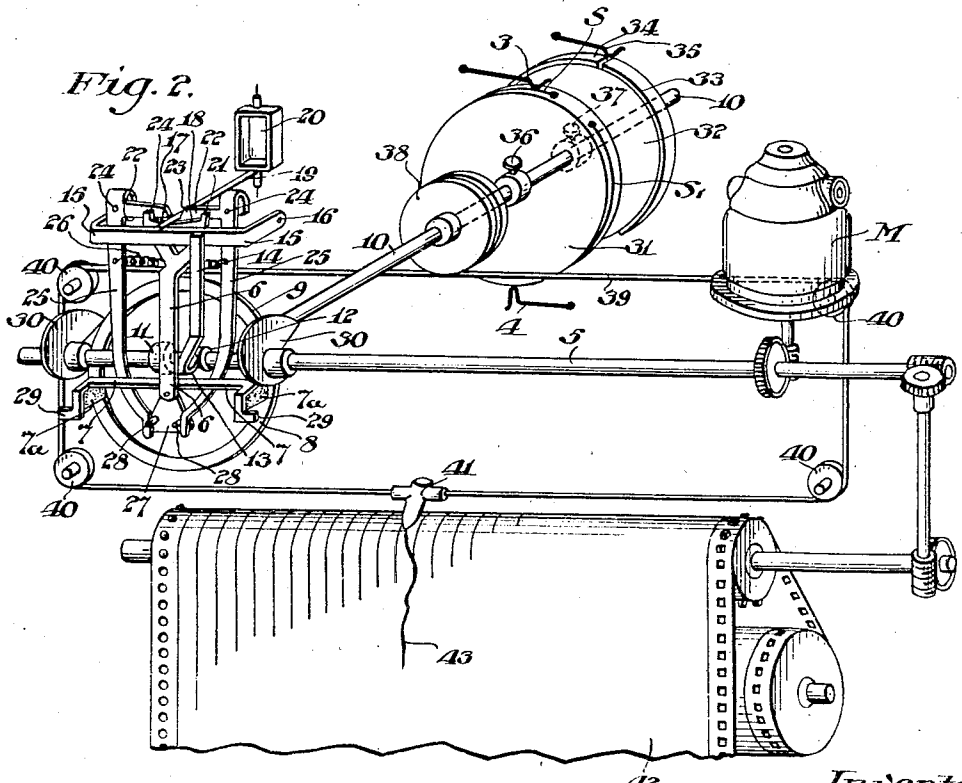


Fig. 2.



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FREQUENCY AND SPEED CONTROL

Original Filed March 27, 1925 2 Sheets-Sheet 2

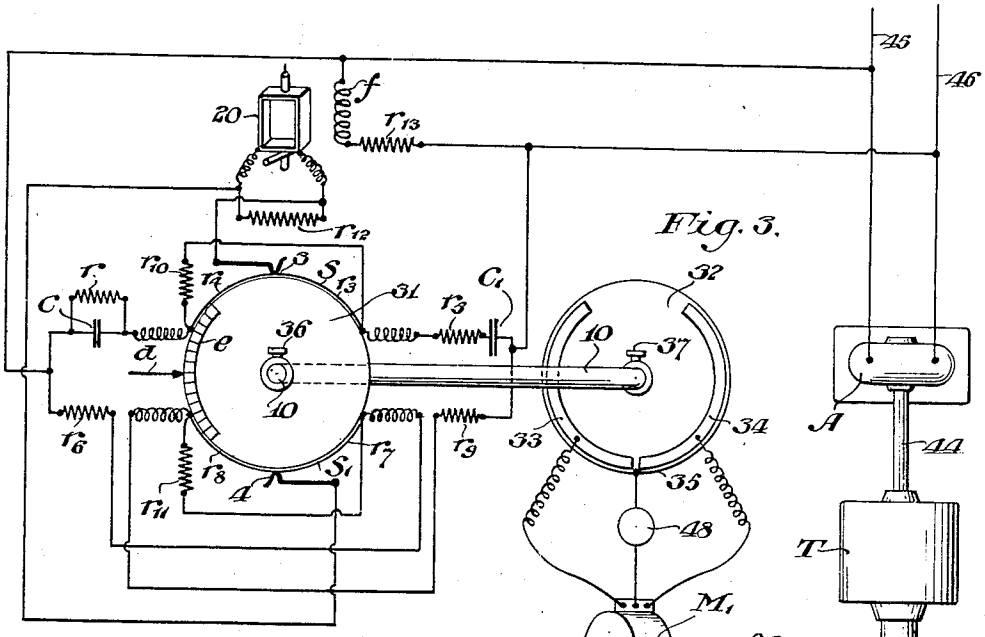


Fig. 3.

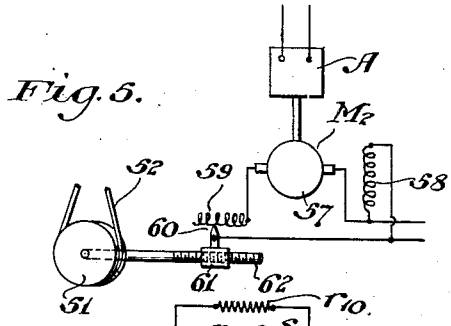


Fig. 5.

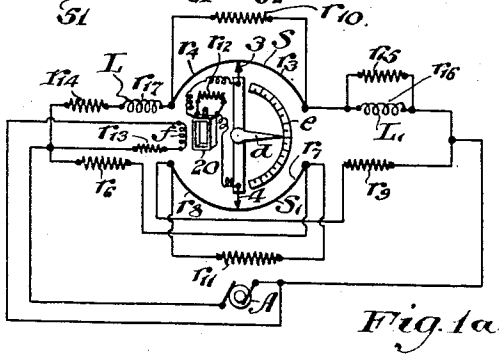


Fig. 1a.

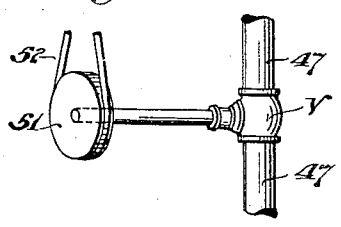


Fig. 4.

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1,751,539

UNITED STATES PATENT OFFICE

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FREQUENCY AND SPEED CONTROL

Original application filed March 27, 1925, Serial No. 18,794. Divided and this application filed June 27, 1928. Serial No. 288,688.

My invention relates to a system of controlling the frequency of a fluctuating or alternating current generator or the speed of a moving system.

In accordance with my invention, to maintain the speed of a moving system substantially constant, variations in frequency of an alternator driven thereby produce effects upon a balanced electrical network, as a Wheatstone bridge, to control the position of means adjustable to vary the speed of said system; more specifically and preferably, the speed of the moving system is kept within certain limits by governor mechanism or equivalent, and the action of the governor is varied in senses and to extents depending upon the magnitudes of the unbalancing effects produced by changes of frequency upon the balanced network.

My invention resides in a method and apparatus of the character hereinafter described and claimed.

For an understanding of my method, and for an illustration of some of the various forms my apparatus may take, reference is to be had to the accompanying drawings, in which:

Fig. 1 is a diagrammatic view of apparatus suitable for practicing my method and embodying my invention in one of its forms; and Fig. 1ª is a modification.

Fig. 2 is a fragmentary perspective view of recording and control mechanism utilizable in accordance with my invention.

Fig. 3 is a diagrammatic view of a system for controlling speed or frequency.

Figs. 4 and 5 are fragmentary views of modified forms of speed or frequency-controlling means.

Referring to Fig. 1, A is a generator or source of alternating or fluctuating current whose frequency is to be measured or indicated. Its terminals are connected, respectively, to the conjugate terminals or points 1 and 2 of a Wheatstone bridge whose other conjugate points are at the points of engagement of the contacts 3 and 4 movable along the slide wires or adjustable resistances S and S′, respectively. In the first bridge arm is included a condenser C, shunted by the non-inductive resistance r; in series with that portion r^4 of the non-inductive resistance S lying to the left of the contact 3. In the second bridge arm are included the condenser C^1, non-inductive resistance r^5, and the non-inductive resistance r^3 constituting the remainder of the resistance S to the right of the contact 3. In the third bridge arm are included the non-inductive resistance r^6 and the portion r^7 of the slide wire resistance S^1 to the right of the contact 4. In the fourth bridge arm are the resistance r^8 constituting the remainder of the resistance S^1 to the left of the contact 4, and the non-inductive resistance r^9.

In case the resistances S and S^1, which may be in the form of simple wires or in the form of helices along which the contacts 3 and 4 move, are not by themselves of exactly correct values, they may, as well understood in the art of slide wires, be shunted by resistances such as r^{10} and r^{11}, respectively, to ensure between their terminals exactly the correct or desired amount of resistance.

It is desirable that all of the resistances aforementioned shall have small or substantially zero temperature co-efficient, to avoid influence of temperature upon the measurements.

While the source A is in one conjugate conductor of the bridge, in the other, between the contacts 3 and 4, is connected the movable coil 20 of a galvanometer having the deflecting pointer or needle 19. The coil winding 20 may, as well understood in the art, be shunted by a resistance r^{12}, of suitable magnitude. The alternating magnetic field of the galvanometer is produced by current from the source A traversing the galvanometer field winding or coil f, in series with which may be connected the resistance r^{13}.

The phase angle of the current exciting the galvanometer field magnet winding f with respect to the impressed electro-motive-force may change or vary from various causes, such, for example, as temperature changes of the winding f, change in magnitude of the impressed voltage, etc. Such a change of phase of the field-exciting current will introduce error in the measurements unless means are provided to make possible a

true balance of the bridge regardless of the shifting of phase of the field-exciting current of the galvanometer. To this end it is essential that three ratios shall be equal for all frequencies within the range to be measured by the bridge. This equality of ratios is expressed by the following equation:

$$\frac{r^1}{r^2}=\frac{d^1}{d^2}=\frac{a}{b} \quad \text{---------- (1)}$$

in which: r^1 and d^1 are, respectively, the resistance and reactance components of one arm of the bridge, as, for example, the aforesaid first arm including C, r and r^4; r^2 and d^2 are, respectively, the resistance and reactance components of another arm of the bridge, for example, the aforesaid second arm including r^3, r^5 and C^1; and a and b are, respectively, the resistances or impedances of the other arms of the bridge, for example, the aforesaid third and fourth arms including, respectively, r^6, r^7 and r^8, r^9.

In the example illustrated in Fig. 1, where condensers are employed, it is desirable and preferable that they be low loss condensers, to avoid phase angle or capacity changes with temperature changes, and are preferably mica condensers of the best type.

The combination of a condenser, as C, with a shunting resistance, as r, is the equivalent or has the characteristics of a condenser having considerable losses, which may be expressed in terms of an equivalent resistance which changes in magnitude with changes in frequency. Accordingly, the aforesaid resistance r^1 is not the actual non-inductive resistance r plus r^4, but is an apparent, fictitious or equivalent alternating current resistance which, however, changes in magnitude with changes in frequency, and comprises not only the resistances r, r^4, but, in addition, the apparent or fictitious resistance corresponding with the losses, if any, of the condenser C per se, and of the combination of the condenser C with its shunting resistance r. The aforesaid resistance r^2 corresponds with the sum of the resistances r^3 and r^5 and the apparent or fictitious resistance, variable with frequency, due to the losses of the condenser C^1, if any. However, when the condenser C^1 is a high grade mica condenser, with low loss, we may write

$$r^2=r^3+r^5 \quad \text{---------- (2)}$$

It is further true that

$$r^1=\frac{r}{1+\omega^2C^2r^2}+r^4 \quad \text{---------- (3)}$$

and

$$d^1=\frac{\omega Cr^2}{1+\omega^2C^2r^2} \quad \text{---------- (4)}$$

and

$$d^2=\frac{1}{\omega C^1} \quad \text{---------- (5)}$$

In Equations (3), (4) and (5), ω (omega) is 2π times the frequency; C and C^1 are, respectively, the capacities of the condensers C and C^1; and r and r^4 are the magnitudes of the resistances r, r^4. Equations (3), (4) and (5) are well known to those skilled in the alternating current art, and from them are determinable the proper values of the several resistances and capacities to be utilized in an arrangement such as indicated in Fig. 1 for measuring a desired range of frequencies, it being understood that the contacts 3 and 4 are moved in unison with each other because attached to the same movable member c carrying the pointer d and co-acting with the stationary scale e calibrated in terms of frequency, speed, or both, or any equivalent of them. The contacts 3 and 4 take a different position for each different frequency, in order to balance the bridge for that frequency, in which event the galvanometer coil 20 is in its zero or non-deflecting position.

From the foregoing, it will be understood that the function of the slide wire S^1 is to change the ratio of the resistances in the third and fourth arms of the bridge in proportion to the change in the ratio of the effective resistance and reactance in the first and second arms of the bridge in order that the equality of ratios expressed in Equation (1) shall obtain, whereby the bridge may be truly balanced regardless of changes of the phase angle of the current in the galvanometer field f.

While measurement of frequency has been described in connection with Fig. 1, it will be understood that speed or any other magnitude proportional to frequency may similarly be measured. For example, the speed of a rotating member may be measured by driving an alternating current generator, as A, by such member, and then measuring the frequency of the current delivered by the generator.

It shall be understood that my invention includes equivalents of the arrangements shown in Fig. 1, for it will be understood that in lieu of or with resistances r^6 and r^9 may be utilized either inductive or capacitative reactances, and that the slide wire S^1 may represent an inductive reactance, variable portions of which are included in the neighboring bridge arms, or may represent complementarily variable capacities included in the neighboring bridge arms. Furthermore, it will be understood that in the first and second bridge arms there may be used inductive reactances, and that the slide wire S may be inductive, or complementarily variable capacities may be connected in the neighboring bridge arms.

In Fig. 1^a is shown such a generally equivalent arrangement in which in the first bridge arm are the serially related inductance L and resistance r^{14}, and in the second bridge arm the inductance L^1 shunted by a

resistance r^{15}. It will be understood that the total resistance of the first arm of the bridge comprises the resistance r^4, the resistance of the conductor of the inductance L, and the resistance r^{14}, which last is present as a separate unit if the resistance of the conductor of of the inductance L is not itself sufficient.

In this case again Equation (1) applies. r^1 and d^1 are the resistance and reactance components of one arm of the bridge, as for example, the first arm including L, r^{17}, r^{14}; r^2 and d^2 are respectively the resistance and reactance components of another arm of the bridge, for example the second arm including r^3, r^{15}, r^{16} and L^1; and a and b, are respectively, the resistances or impedances of the other arms of the bridge, for example the third and fourth arms including respectively r^6, r^7 and r^8, r^9.

$$r^1 = r^{14} + r^{17} + r^4$$

$$d^1 = \omega L$$

$$r^2 = \frac{r^{15} r^{16^2} + r^{15^2} r^{16} + \omega^2 L^{1^2} r^{15}}{(r^{15} + r^{16})^2 + \omega^2 L^{1^2}} + r^3$$

$$d^2 = \frac{\omega L^1 r^{15^2}}{(r^{15} + r^{16})^2 + \omega^2 L^{1^2}}$$

$$a = r^6 + r^7 \quad b = r^8 + r^9$$

r^{16} = resistance of inductance L^1

r^{17} = resistance of inductance L

The arrangement of Fig. 1, or equivalent thereof, is utilizable for recording and controlling frequency and speed by recourse to any suitable recording and control mechanism, one example of which is illustrated in Fig. 2, and corresponding with a structure of the character disclosed in prior Letters Patent of the United States to Leeds No. 1,125,699, January 19, 1915.

Referring to Fig. 2, M is an electric motor or other suitable source of power rotating the shaft 5 at substantially constant speed. A lever 6 is pivoted at its upper end on a horizontal axis and has pivoted thereto on a horizontal axis at its lower end the arm 7, on each end of which is a shoe 7^a, of cork or the like, frictionally engaging the rim 8 of the clutch disc or wheel 9, secured upon the shaft 10 of the movable structure or system. Secured upon the shaft 5 is a cam 11, which periodically engages the lever 6 and moves it outwardly, in opposition to a spring, not shown, thereby lifting the shoes 7^a from the rim 8, the spring returning the shoes into engagement with the rim after predetermined rotation of the cam 11. Upon the shaft 5 is secured a second cam 12, which, after the shoes 7^a have been lifted from the rim by the cam 11, actuates the finger 13 on the lower end of the arm 14 secured at its upper end to the member 15 pivoted on a horizontal axis at 16. Upon the member 15 is secured the member 17, whose upper edge 18 is inclined outwardly from the center. Disposed immediately above the edge 18 is the aforesaid needle or pointer 19 of the alternating current galvanometer whose coil is 20. At the opposite ends of the member 17 are the abutments 21 for limiting the deflection of the needle 19. Directly above the needle 19 and beneath which it normally freely swings are the edges 22, preferably straight and horizontal, upon the members 23, 23 pivoted at 24, 24, and extending toward each other, leaving a gap of sufficient width between their inner ends for free entry of the needle 19 when in balanced or zero position, corresponding with a balance of the Wheatstone bridge of the character shown in Figs. 1 and 3. The needle 19 normally swings freely between the edge 18 and the members 23, 23, which latter have downwardly extending arms 25, 25, biased toward each other by the spring 26. Attached to the lower end of the arm or lever 6 is a triangular plate 27 carrying the pins 28, 28, co-operating with the lower ends of the members 25, 25. At opposite ends of the arm 7 are the lugs 29, 29, adapted to be engaged by the cams 30, 30, similar in shape and similarly positioned and secured upon the shaft 5.

As the galvanometer needle 19 deflects in the one direction or the other, the shaft 10 will be rotated in the one direction or the other, and to an extent corresponding to the extent of the galvanometer deflection. For example, when the needle 19 deflects to the right, Fig. 2, due to periodic vertical movement of member 15 by cam 12, the needle 19 is clamped between the inclined edge 18 and lower edge 22 of the right hand member 23 causing the arm 25 to be tilted in a clockwise direction about its pivot 24, thereby pushing the right hand pin 28 on plate 27, and so tilting the movable or driving clutch or arm 6 in a clockwise direction while cam 11 is holding shoes 7, 7 from the rim 8 of clutch wheel 9, the angular movement of the member 6 being dependent upon the degree of deflection of needle 19. The cam 11 soon thereafter allows the shoes to again grip the rim 8 of wheel 9 and soon thereafter the left hand cam 30 engages the ear 29, which has been elevated, pushing it downwardly due to rotation of shaft 5, to restore it to the horizontal position indicated, but in so moving back to normal position the clutch member rotates the disc 9 and shaft 10 affixed thereto in a counter-clockwise direction.

Secured upon the shaft 10 is a disc 31 of insulating material, carrying upon its periphery the aforesaid resistances or impedances S, S^1, which in this example, as indicated in Fig. 3, are rotated, while their co-acting contacts 3 and 4 are stationary. Secured upon the shaft 10 is a second disc 32 carrying the arcuate contacts 33 and 34, with which co-acts the stationary contact or brush 35. The discs 31 and 32 are adjustable to any

suitable angles with respect to each other and with respect to the shaft 10 by suitable set screws 36 and 37.

Secured upon the shaft 10 is the grooved pulley wheel 38, around which is wrapped the cord 39, which passes over the idler rollers 40 and has attached thereto the pen or marker 41 for drawing upon the record sheet or paper 42 a mark or record 43, of the changes of frequency or speed. The paper 42 is driven by the motor M, as well understood in the art. Disc 31 may carry the frequency or speed scale *e* co-acting with stationary pointer *d*.

Referring to Fig. 3, the movable structure or system of Fig. 2 is shown in so far as it comprises the shaft 10 and the discs 31 and 32. The slide wires S, S^1 are comprehended in a Wheatstone bridge of the character indicated in Fig. 1.

A turbine or other source of power, or generically a rotating system, T, drives the alternating current generator or source A related to the bridge of Fig. 3 as the source A is related to the bridge in Fig. 1. The source A in this instance may be a small alternating current generator driven by the rotary structure T through the shaft 44 for purposes merely of measuring or controlling the speed of the device T. Or it may be an alternating current generator of large capacity for supplying current to any suitable load connected to the supply circuit conductors 45 and 46, in which case the frequency or speed of T and A may be controlled by controlling the opening of the valve V controlling the rate of supply of motive fluid or steam through the pipe 47 to the turbine T. In this case the brush 35 with contacts 33 and 34 control the reversible electric motor M^1 receiving current from any suitable source, as 48. When the disc 32 is in the position indicated in Fig. 3, the motor M^1 is de-energized, and this condition corresponds with balance of the Wheatstone bridge for the desired speed or frequency of the turbine T or generator A. Should the speed or frequency rise, the Wheatstone bridge will be unbalanced, causing a deflection of the galvanometer and its needle 19, causing in turn a rotation of the shaft 10 to an extent corresponding with the extent of unbalance of the bridge, and in such direction that the contact 33, for example, will be brought into engagement with the contact 35, energizing the motor M^1 which runs in a certain direction, rotating the shaft 49, through any suitable gear reduction, generically represented by the pulleys 50, 51 and belt 52, thereby causing the member 53 to advance upwardly along the threaded shaft 49, carrying the abutment 54 upwardly, with resultant tendency to compress the spring 55, which opposes the fly ball governor 56, driven by the turbine or device T, to partially close the valve V, causing reduction in speed and frequency. Similarly, when the frequency or speed diminishes, the motor M1 will be energized through contacts 34 and 35, and will rotate in the opposite direction, and effect an increase in the opening of the valve V, with resultant increased speed and frequency. In both cases the speed or frequency is varied or changed toward the desired frequency, at which the contact 35 is in engagement with neither of the contacts 33 and 34, and the bridge is in balance at the desired frequency. When the frequency or speed changes from the desired magnitude, the Wheatstone bridge is unbalanced, the galvanometer deflects, and the discs 31 and 32 are rotated by the shaft 10 in a direction tending to rebalance the bridge at the impressed frequency and cause a change in the speed or frequency back toward the desired magnitude. When the desired frequency is reached or obtains the bridge balances itself at that frequency and the motor M^1 is de-energized.

The governor 56, or its equivalent, at a given setting, or position of abutment 54, is effective of itself to maintain the speed of the system or frequency of the alternator within a range of variation broader than is suitable or desirable. In the arrangement described, by modifying automatically in accordance with change of frequency the action or setting of the governor, the range of variation of speed or frequency is materially reduced to a practically negligible amount. The speed or frequency may be considered substantially constant, less than $\frac{1}{10}$ of 1% variation being obtained in actual practice.

At the same time, the automatic system produces a record of the speed or frequency upon the record paper 42, or indicates speed or frequency by scale *e* on disc 31.

In lieu of the valve control mechanism indicated in Fig. 3, there may be utilized that indicated in Fig. 4, where through suitable reducing gearing, the motor M^1 rotates the valve stem to effect partial closure or opening of the valve V upon increase or decrease of speed or frequency. In either of the valve arrangements of Figs. 3 and 4, it will be understood that the valve may be either in the main steam or motive fluid line, or may be in a by-pass, and that the governor 56 of Fig. 3 may be either the main governor or an auxiliary governor of the turbine T.

In Fig. 5 there is fragmentarily indicated an alternating current generator or source A, either solely for speed measurement, or for supplying current to a consumption circuit, as in Fig. 3. In this case, however, the turbine T is replaced by an electric motor M^2, such, for example, as a shunt motor, having the armature 57 and shunt field 58, with a variable resistance 59 in the armature circuit, or in the field circuit if desired, and adjusted by the contact 60 moved by the nut 61 movable along the threaded shaft 62 driven

through suitable reduction gearing by the reversible motor M^1 of Fig. 3.

In the operation of a frequency or speed control system of the character hereinbefore described, the frequency of an alternating or fluctuating current is in effect determined or measured, as in the case of Figs. 1 and 1^a, or equivalent, and in addition, a frequency or speed control is effected.

It will be further understood that my invention is not limited to control of frequencies of 25, 60 or more cycles per second as commonly utilized on power and lighting circuits, but comprehends also control of higher frequencies, including the so-called high or radio frequencies.

For brevity in the appended claims, the term "frequency" is employed in a generic sense to include frequency, speed, or equivalent magnitude proportional to or dependent upon frequency or speed.

This application is a division of my copending application Serial No. 18,794, filed March 27, 1925.

What I claim is:

1. In a system comprising a Wheatstone bridge having combinations of resistance and reactance in different bridge arms and movable structure associated with said bridge, the method of controlling frequency, which comprises impressing a fluctuating current representative of the frequency to be controlled upon said Wheatstone bridge, effecting movement of said structure in response to and to an extent dependent upon the degree of unbalance of the bridge, effecting by said movement variation of the relative magnitudes of impedances in the bridge arms toward equality between the ratio of the resistance components of two arms of the bridge, the ratio of the reactance components of said arms of the bridge, and the ratio of the impedances of the other arms of the bridge, and varying the frequency of said current by said movement.

2. Apparatus for controlling frequency, comprising a Wheatstone bridge having combinations of reactance and resistance in different bridge arms, impedances in the other bridge arms, a source of fluctuating current in a conjugate conductor of said bridge, a fluctuating current galvanometer in the other conjugate conductor of said bridge, means for exciting the galvanometer field from said source, movable structure controlled by said galvanometer when said bridge is unbalanced, and means controlled by said movable structure for adjusting the relative magnitudes of impedance in the different pairs of bridge arms toward equality between the ratio of the resistance components of said first named arms of said bridge, the ratio of the reactance components of said first named arms of said bridge, and the ratio of the impedances of said other arms of said bridge, and means for varying the frequency of the current from said source controlled by said movable structure.

3. In a system comprising a moving system, an alternator driven thereby, an electrical balancing network, and means controlling energization of said moving system, the method of controlling the speed of said moving system which comprises, producing unbalance of said electrical network by departure of the frequency of the alternator from a predetermined frequency at which the network is balanced, and utilizing the unbalanced network to modify the action of said means to control delivery of motive energy to said system in a sense and to an extent more or less completely to compensate for said departure.

4. In a system comprising a moving system, means for regulating delivery of energy thereto to maintain the speed within a range, an alternator driven by said system, and an electrical balancing network, the method of controlling the speed of the moving system, which comprises producing unbalance of said electrical network by departure of the frequency of said alternator from a predetermined frequency at which the network is balanced, and utilizing the unbalanced network to modify the action of said regulating means.

5. In a system comprising an alternator, an electrical balancing network, and movable structure associated with said network, the method of controlling the frequency of the alternator which comprises impressing a fluctuating current representative of said frequency upon said network balanced at a predetermined frequency, effecting movement of said structure in response to and to an extent dependent upon the degree of unbalance of the network, and effecting by said movement variation in the magnitude of motive energy applied to said alternator.

6. In a system comprising an alternator, an electrical balancing network, and movable structure associated with said network, the method of controlling the frequency of the alternator which comprises impressing a fluctuating current representative of said frequency upon said network balanced at a predetermined frequency, effecting movement of said structure to rebalance said network upon and in response to departure of the frequency from said predetermined frequency, and producing by said movement variation in the magnitude of motive energy applied to said alternator in a sense and to an extent to compensate for said departure.

7. In a system comprising an alternator, a Wheatstone bridge having combinations of resistance and reactance in different bridge arms, movable structure associated with said bridge, and mechanism related to said structure controlling motive energy applied to said alternator, the method of controlling the fre-

quency of the alternator which comprises impressing a fluctuating current representative of said frequency upon said Wheatstone bridge, effecting movement of said structure in response to and to an extent dependent upon the degree of unbalance of the bridge, and controlling by said movement the position of said mechanism regulating the magnitude of motive energy applied to said alternator to affect the speed thereof.

8. A system of control comprising an alternator whose frequency is to be controlled, motive means driving said alternator, an electrical balancing network upon which is impressed a fluctuating electro-motive-force representative of the frequency of said alternator, said network balanced at a predetermined frequency, movable structure associated with said network actuated upon unbalance of the same in response to a different frequency of said electro-motive-force, and means controlled by said structure for varying the speed of said motive means to correct the frequency of said alternator.

9. A system of control comprising an alternator whose frequency is to be controlled, motive means driving said alternator, governing means for maintaining the speed of said motive means within a range of predetermined limits, an electrical balancing network upon which is impressed a fluctuating electro-motive force representative of the frequency of said alternator, said network balanced at a predetermined frequency, movable structure associated with said network actuated upon unbalance of the same in response to a different frequency of said electro-motive-force, and means controlled by said structure coacting with said governing means to modify its action whereby the frequency of said alternator is maintained substantially constant.

10. A system comprising an alternator, a prime mover therefor, a governor maintaining the speed of said prime mover substantially constant, and means for determining the governor setting comprising an electrical network responsive to the alternator frequency and means operable when the network is not balanced at a predetermined frequency to change the setting of said governor.

11. Apparatus for controlling frequency comprising a Wheatstone bridge having combinations of reactance and resistance in different bridge arms and impedances in other bridge arms, an alternator in one conjugate conductor of said bridge, electro-responsive means in the other conjugate conductor, structure controlled by said electro-responsive means when said bridge is unbalanced for adjusting the relative magnitudes of impedance in the different pairs of bridge arms toward balance of said bridge at alternator frequency, and means effective when said structure is displaced from a predetermined position to vary the alternator speed in a sense decreasing the difference between the actual alternator frequency, and the desired frequency.

12. Apparatus for controlling frequency comprising a Wheatstone bridge responsive to the frequency of an alternator in circuit therewith, deflecting means responsive to unbalance of said bridge, structure moved by said deflecting means to an extent and in a sense from a predetermined position dependent upon the unbalance and means effective when said structure is displaced from said predetermined position for varying the speed of the alternator to restore balance.

13. An arrangement comprising an alternator, a prime mover therefor, a power supply circuit connected to said alternator, a governor for maintaining the speed of said prime mover substantially constant, a system balanced at a predetermined frequency including a Wheatstone bridge connected to said alternator, and means associated with said system actuated in accordance with unbalance thereof to change the governor setting in a sense and to an extent dependent upon the sense and extent of unbalance of said system.

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