

July 20, 1937.

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2,087,326

STANDARD FREQUENCY SYSTEM

Filed Sept. 22, 1934

8 Sheets-Sheet 1

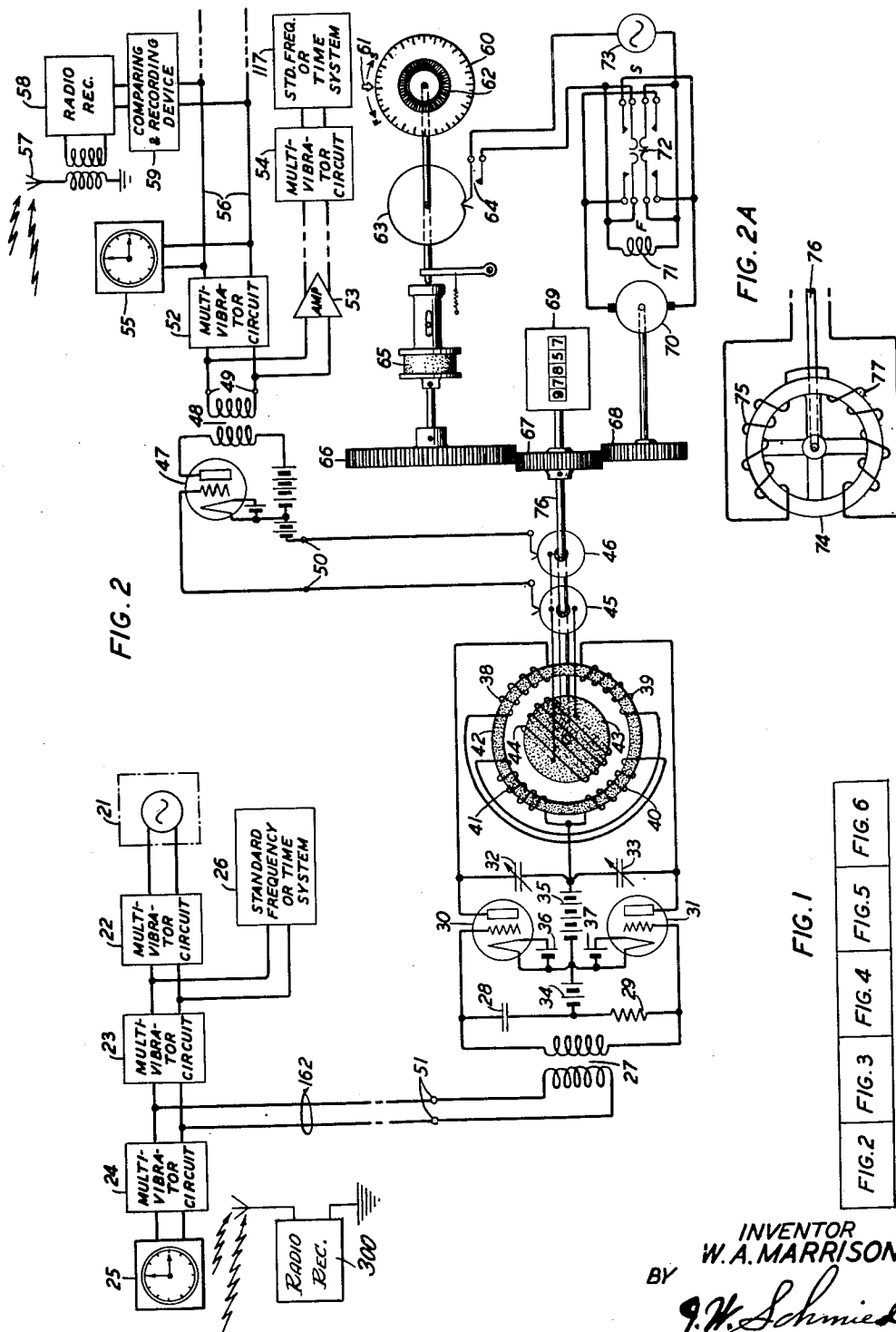


FIG. 1

FIG. 2A

FIG. 2	FIG. 3	FIG. 4	FIG. 5	FIG. 6
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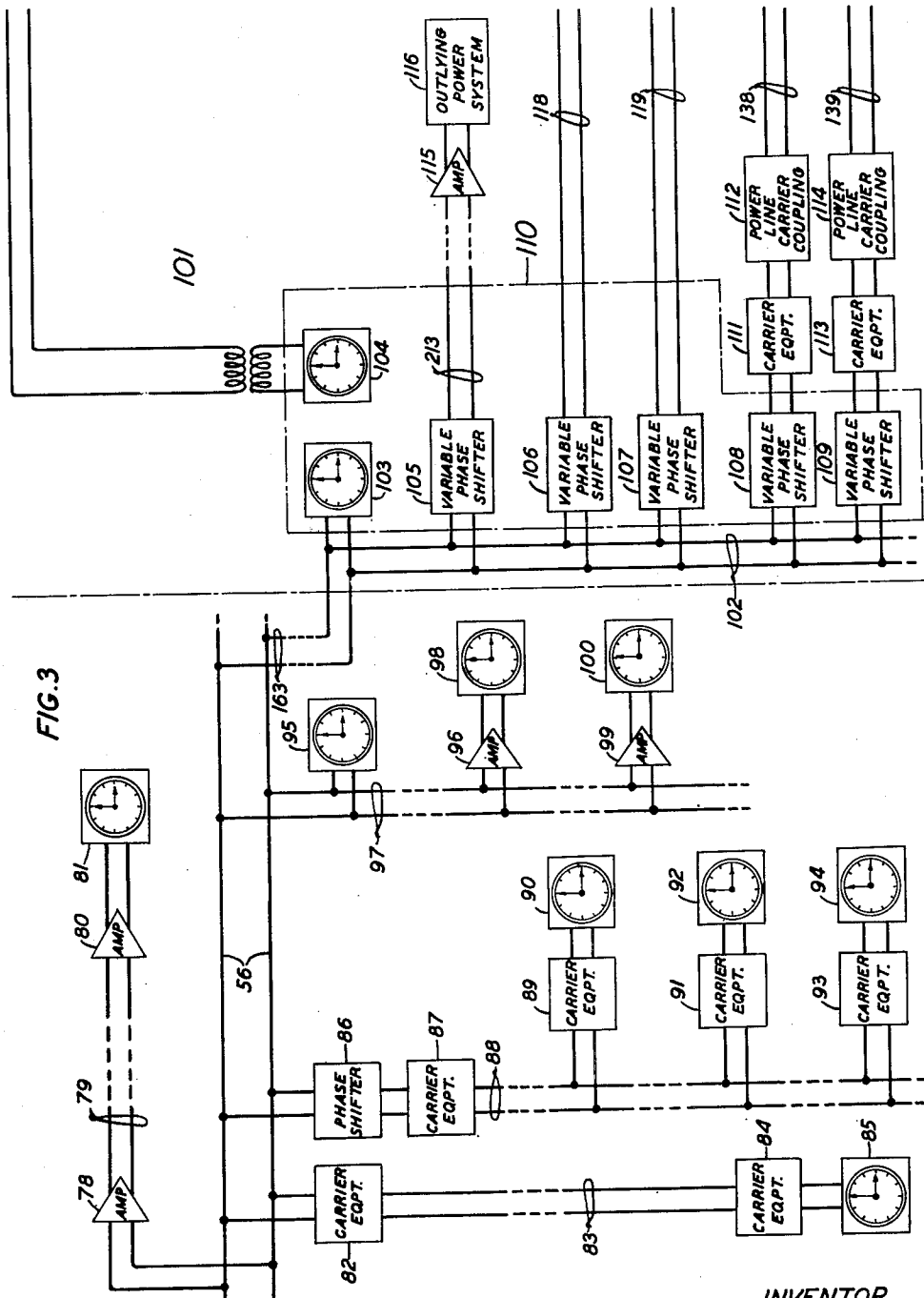
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Filed Sept. 22, 1934

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FIG. 3



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8 Sheets-Sheet 3

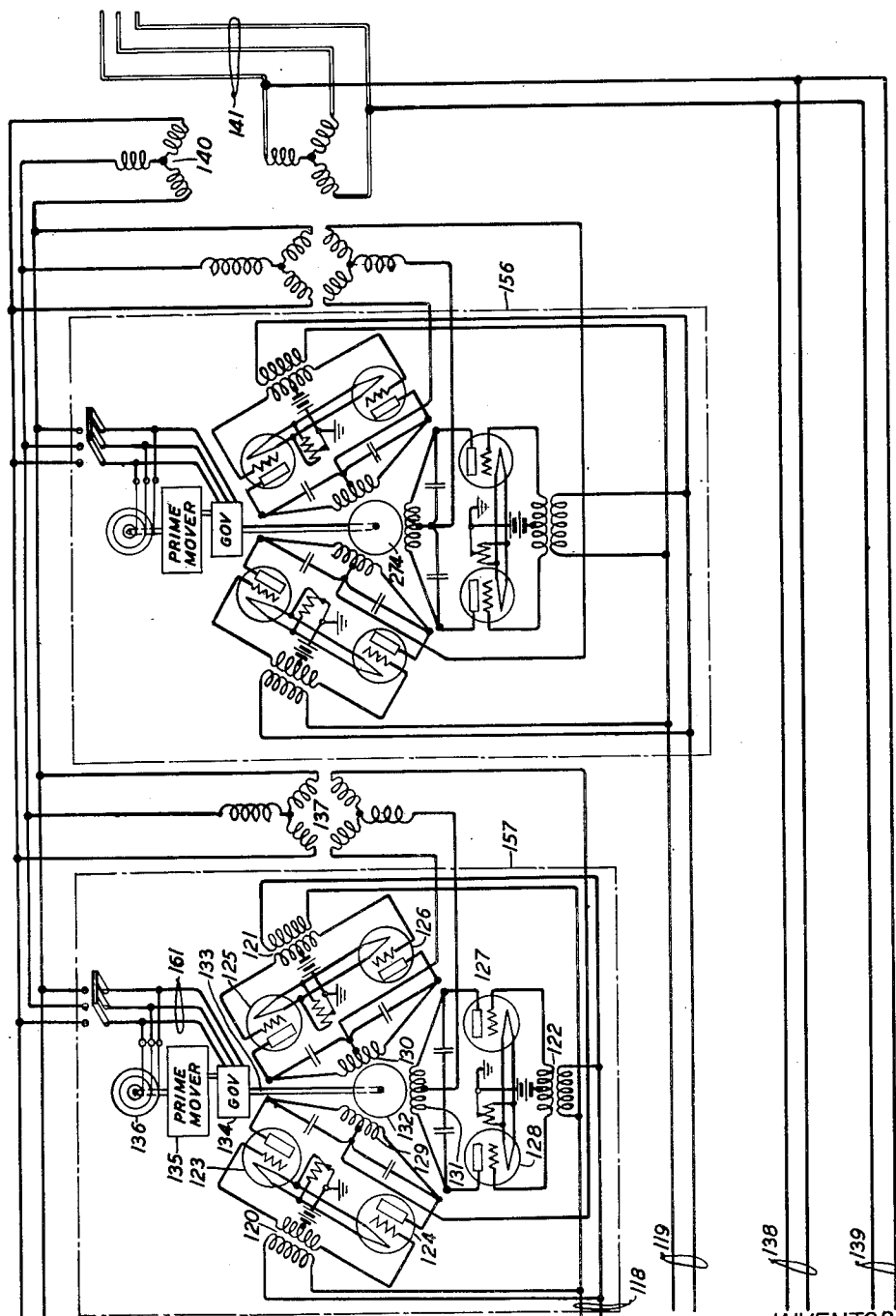


FIG. 4

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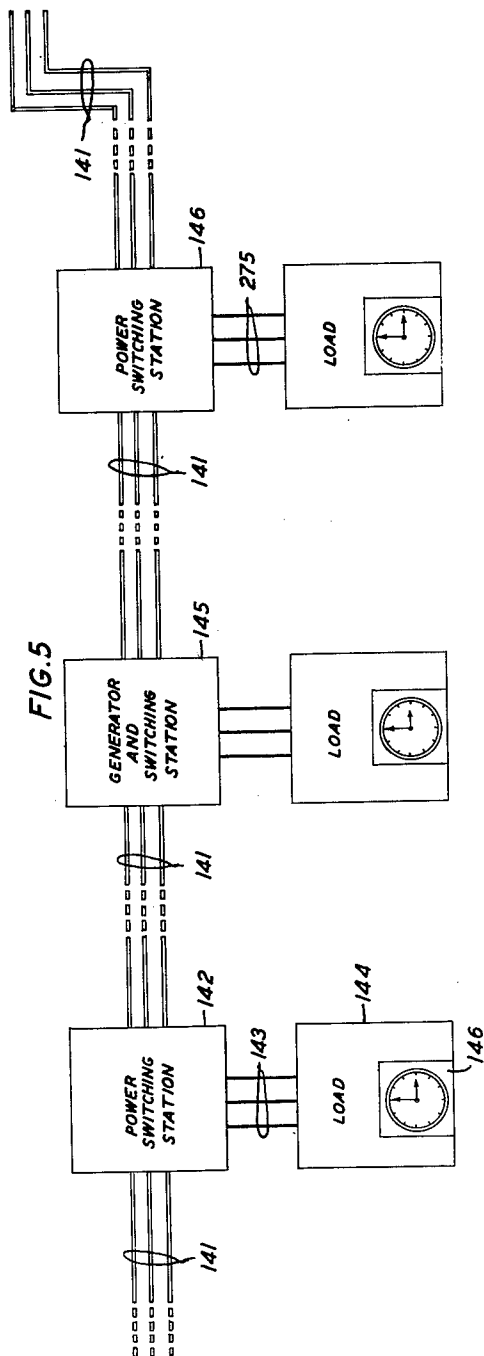
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STANDARD FREQUENCY SYSTEM

Filed Sept. 22, 1934

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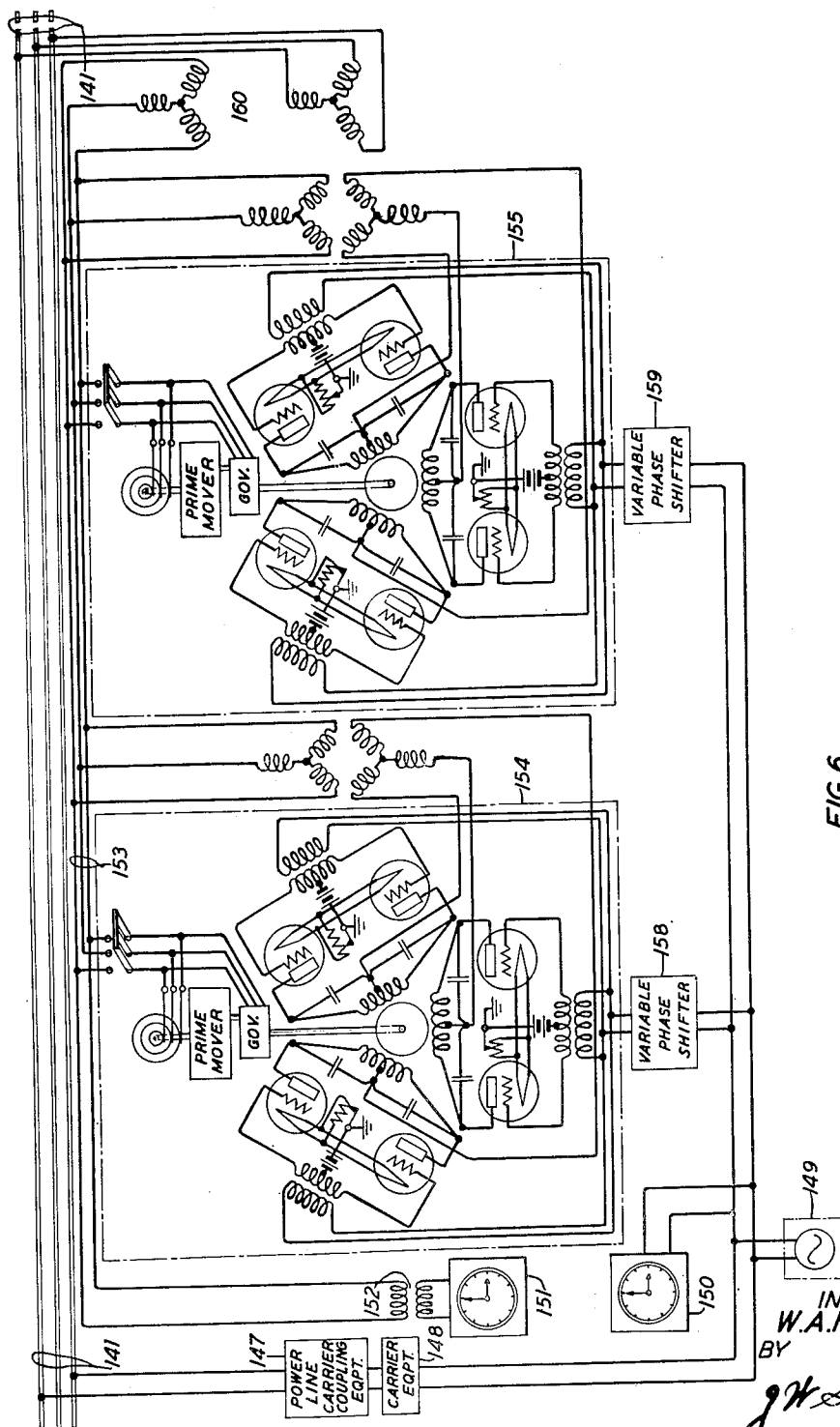
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2,087,326

STANDARD FREQUENCY SYSTEM

Filed Sept. 22, 1934

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July 20, 1937.

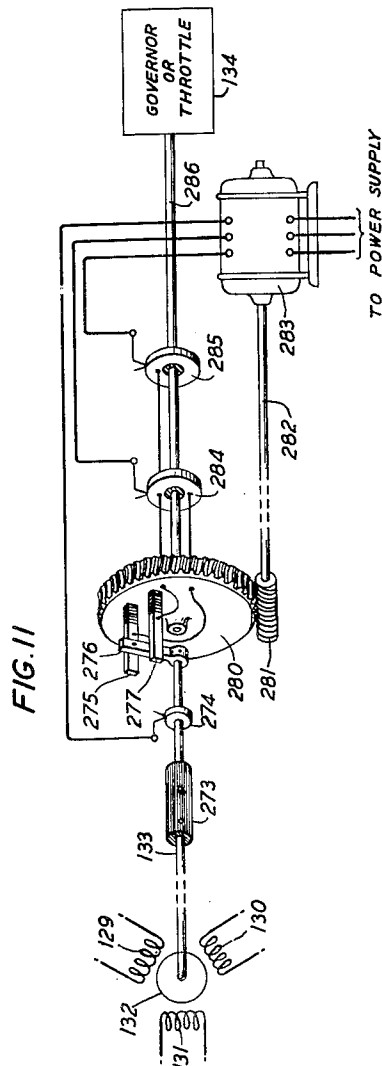
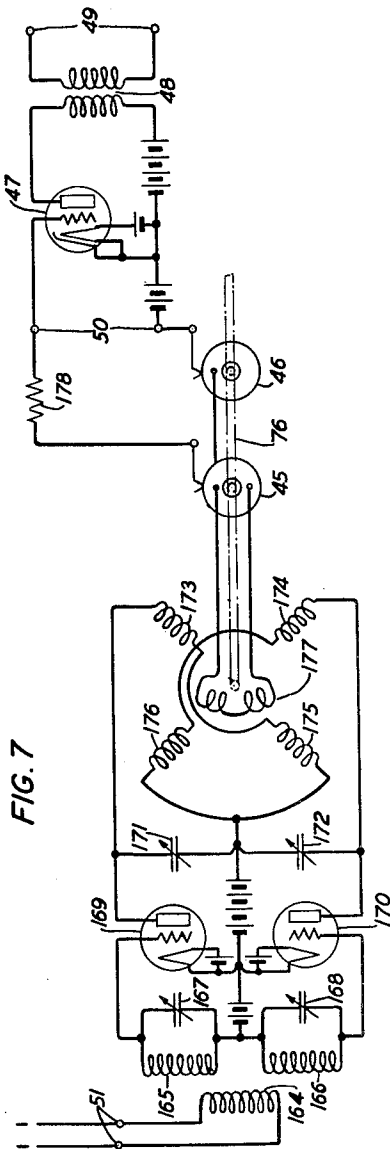
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Filed Sept. 22, 1934

8 Sheets-Sheet 6



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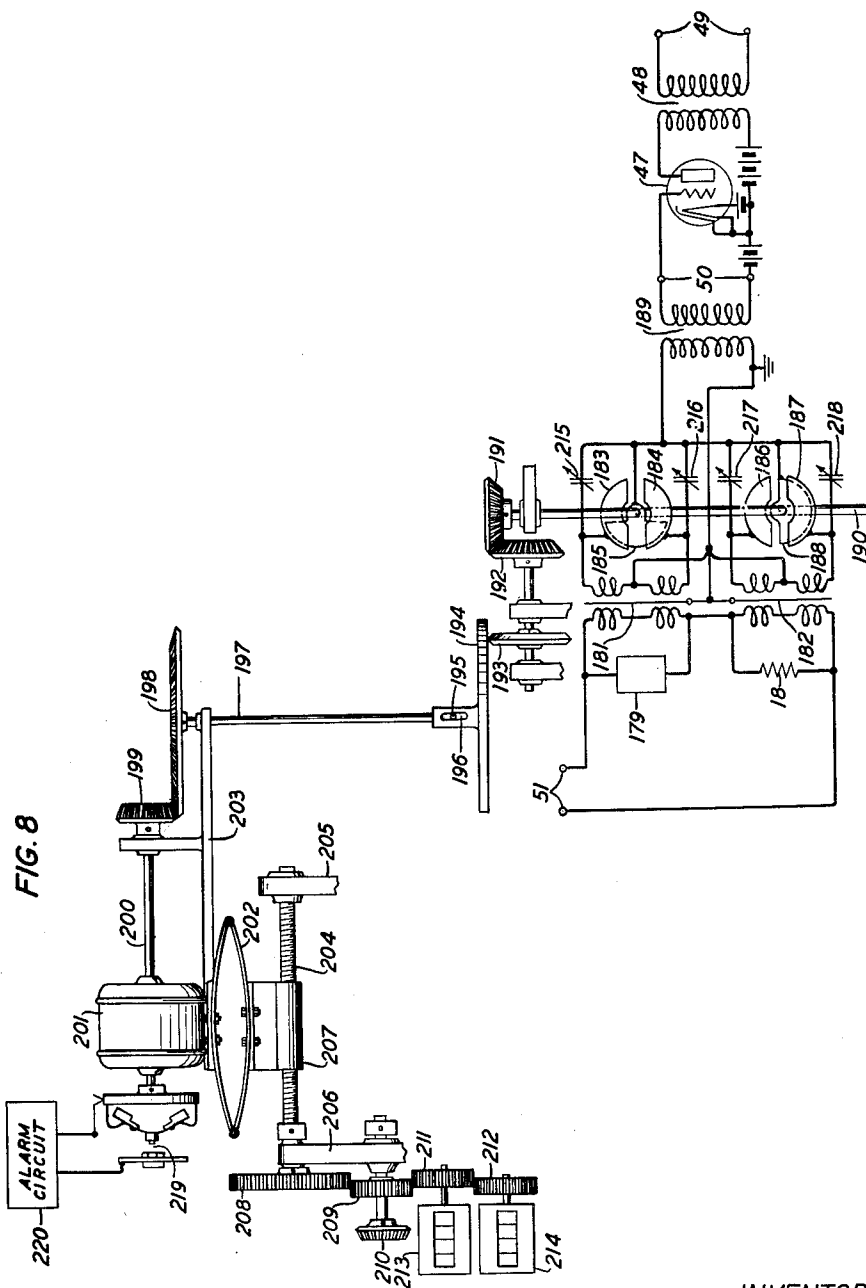
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Filed Sept. 22, 1934

8 Sheets-Sheet 7



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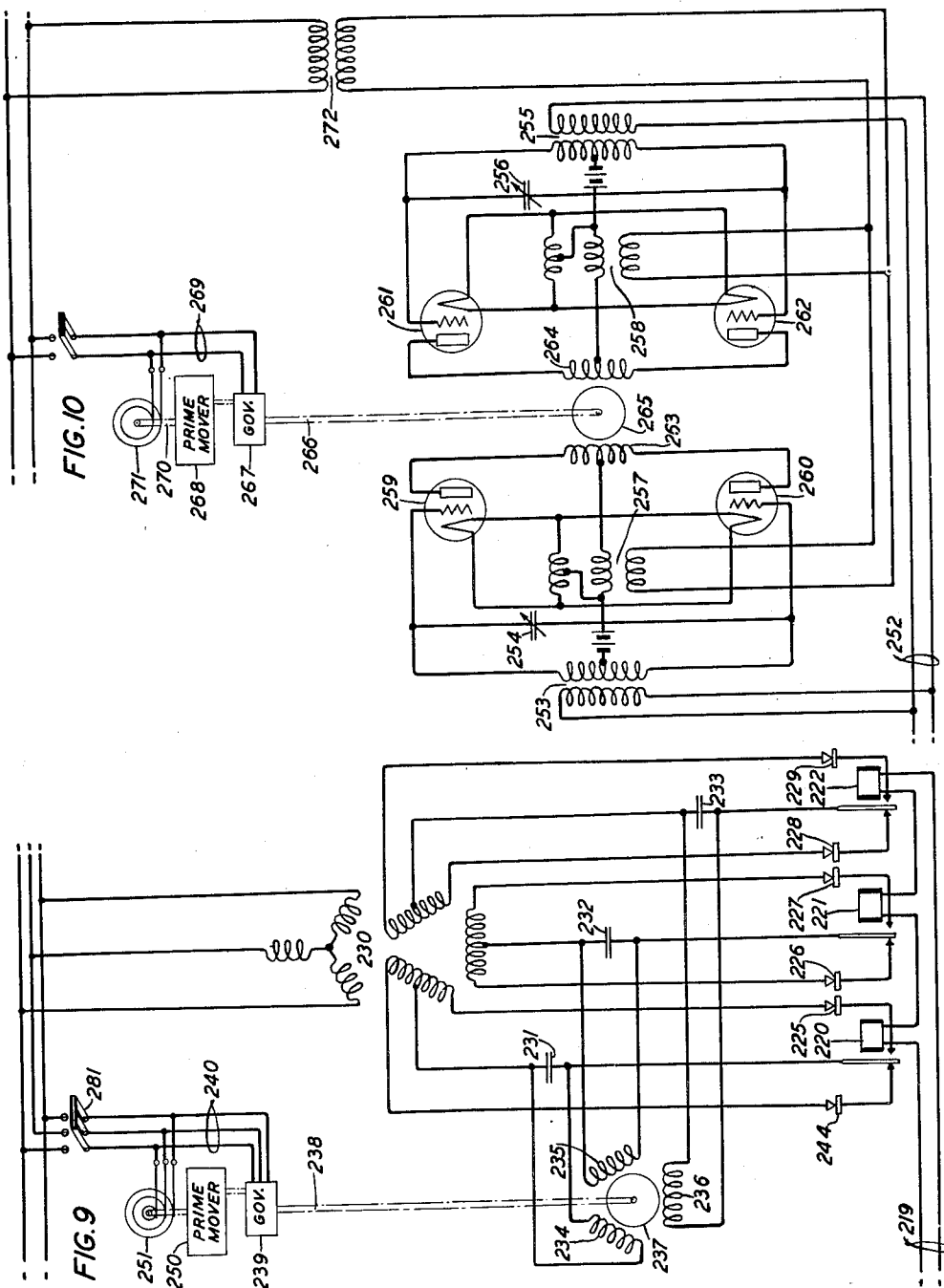
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Filed Sept. 22, 1934

8 Sheets-Sheet 8



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2,087,326

STANDARD FREQUENCY SYSTEM

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Application September 22, 1934, Serial No. 745,098

24 Claims. (Cl. 290—4)

This invention relates to standard or constant frequency systems and more particularly to regulating the phase of the standard frequency current.

The invention also relates to the application of this phase regulated standard frequency current to indicate the correct time and to control the frequency and regulate the integrated phase of an alternating current power supply network so that the frequency of this power supply system may be utilized in devices to indicate the correct time.

In standard or constant frequency systems, various means and devices are employed to prevent any change in the frequency thereof. It is therefore very difficult, undesirable and, in some cases, impracticable, to readily adjust the phase of the output current of such a system in any desired manner to conform to different sets of conditions.

It is the object of this invention to provide a phase adjusting or regulating device which will adjust the phase of an alternating current either continuously and uniformly or intermittently at any uniform and specified rate through any phase angle however large so that the phase of the standard frequency current may be regulated in any desired manner to conform to any set of specified conditions as, for example, time signals.

A feature of the invention is that means are provided to substantially eliminate the effect of stray fields and couplings upon the phase regulating device.

Still another feature of the invention is that changes in the output of the phase regulating or adjusting device or changes in its load impedance are prevented from affecting the phase or frequency of its output current.

Furthermore, the frequency of an alternating current power supply system when used to furnish time service is usually compared with a master clock and is adjusted either automatically or manually in accordance with this clock so that clocks run from the power system will indicate the same time as the master clock. This master clock will vary some from the correct time so that it will be necessary to set it from time to time. When the phase and frequency of the power system is manually adjusted in accordance with a master clock, this clock may be set by time signals or in accordance with any other observations and the frequency and phase of the power system manually regulated in accordance with the clock. However, when it is desired to automatically control the frequency and phase

of the power supply system in accordance with a master clock, it is very difficult to correct or set the master clock in accordance with time signals and, at the same time, have the clocks connected to the power system also automatically set to indicate the correct time in accordance with the master clock. This is particularly true when the power system is large and has many motors and generators connected to it since it is impossible to change in a rapid or abrupt manner either the angular velocity or relative angular position of the large rotating masses of the generators and motors connected to the power system.

A further object of this invention, therefore, is to provide a system for controlling the frequency and regulating the phase of a power system by varying or regulating the phase of a standard or control frequency in accordance with time signals and then controlling the frequency and regulating the integrated phase of a power supply system in accordance with the phase and frequency of this phase regulated standard or control frequency. In this manner, it is possible to automatically set and regulate the power supply frequency so that all the electric clocks driven by synchronous motors which are connected to it will be automatically adjusted and set in accordance with time signals so that they will indicate the correct time.

A feature of the invention is that means are provided to regulate the frequency and relative phase of any and all of the generators connected to the power supply system in any desired manner from the central station.

A further feature of the invention is that the distribution or division of load between the various power houses, power generators and power generators of the power system may be controlled from a central switching point to reduce the circulating current and power in the connecting tie lines between the various generating stations.

Another object of this invention is to provide an improved and simplified modulating arrangement for comparing the frequency and phase of a standard frequency current and the frequency and phase of a polyphase alternating current power system.

A feature of this modulating arrangement is that it may employ gas-filled glow discharge or "thyatron" type tubes.

A further object of this invention is to provide a flexible and reliable standard frequency distribution system for distributing standard fre-

quency current to a large number of clocks and power systems.

A feature of this invention is that means are provided to automatically compensate for variations in the distribution system due to weather changes.

In brief, the invention provides a source of constant frequency current such as disclosed by W. A. Marrison in U. S. Patent 1,784,844, December 16, 1930 and W. A. Marrison Patent 1,935,325, November 14, 1933, both of which are hereby made part of this description as if fully included herein.

The standard frequency current then passes through a phase regulating device. This device comprises a phase splitter for securing currents of two phases, each phase of which is supplied to the input circuit of a vacuum tube. Outputs from these two tubes are then used to secure a rotating magnetic field in which a pick-up coil may be rotated in any desired manner at a designated speed so that the currents of the desired frequency and phase are induced in it. This coil is then connected to the output of the phase regulating and adjusting device through a third vacuum tube amplifier which eliminates the effect of variations of the load impedance on the frequency and phase of the output current.

This phase regulated standard frequency current may then be employed to run a large number of electric clocks which are driven by synchronous motors. Time indicated by these synchronous clocks may then be automatically and simultaneously adjusted in accordance with time signals by the operation of the phase adjusting or regulating device.

This phase regulated standard frequency current may also be used to control the frequency and regulate the phase of a power supply system. To accomplish this, the phase regulated constant frequency current is transmitted to the various power houses either over a power line carrier system or by a special line. At these power houses, the standard frequency current is compared by means of a modulating device with the phase and frequency of the power current generated at the respective power houses. If desired, the comparing or modulating device may be coupled so as to control either the throttle or the governor of the prime movers driving the generators located at the power house so that the frequency and phase of the power supply system is controlled in accordance with the phase and frequency of the regulated standard frequency current. In order to insure continuity of service it may be desirable to provide a secondary standard of constant frequency current at each of the power houses which are also controlled by the standard frequency current received over the line. This secondary standard will supply the control frequency for the power system in case the supply of the standard frequency current transmitted to the power house, for any reason, is interrupted.

It is to be understood that a similar secondary frequency standard source may be provided at any of the clock or frequency systems connected to or controlled by the standard frequency. It may also be desirable to provide these secondary standard systems at various points in the standard frequency distribution network.

By transmitting this phase regulated constant frequency current to the various generating stations or generators of a system at relatively different phase angles, the division of load between the various generators and power houses may be

readily controlled so that any desired load distribution may be secured and maintained. If it is desired, this control may be secured from any centralized control point by providing phase regulating devices at this control point which regulate the phase of the standard frequency current transmitted to each of the power houses of the system.

These and other features of the invention may be more readily understood from the following description of several embodiments of the invention when read with reference to the drawings, in which:

Fig. 1 shows the arrangements of Figs. 2 to 6;

Figs. 2 to 6 illustrate details of a standard frequency system, the phase and frequency of which is adjusted in accordance with time signals and employed to operate a number of clock systems as well as to regulate the phase and frequency of alternating current power supply systems;

Figs. 2—A, 7 and 8 show an alternative phase adjusting and regulating means to that shown in Fig. 2. The arrangement shown in Fig. 8 is similar to the arrangement shown in a patent application of L. A. Meacham, Serial No. 686,352, filed August 23, 1933, which issued as Patent 2,004,613 on June 11, 1935;

Figs. 9 and 10 show alternative modulating circuits for regulating the frequency of a power system in accordance with the standard frequency; and

Fig. 11 shows one method of increasing the torque of the control motor in case considerable torque is required to operate the throttle or governor of a prime mover in the power system.

A general description of a typical standard frequency system, in accordance with this invention, will now be given with reference to Figs. 2 to 6 of the drawings when arranged in accordance with Fig. 1. Starting with Fig. 2, 21 represents a source of standard or constant frequency alternating current. This source may be of any convenient or suitable form as, for example, those illustrated by W. A. Marrison in U. S. Patents 1,784,844, December 16, 1930 and 1,935,325, November 14, 1933. This source may contain one or more alternating current generators and means for comparing the relative frequencies of the various generators as disclosed in the patents above referred to. The frequency of the output of source 21 may be changed by multi-vibrator circuit 22 which may be of any suitable form well known in the art, such as disclosed in a patent application of L. A. Meacham, Serial No. 734,085 filed July 7, 1934 which issued as Patent 2,022,969 on December 3, 1935, in U. S. patent to B. Van der Pol 1,744,935, January 28, 1930, or by L. M. Hull and J. K. Clapp in the Proceedings of the Radio Engineers on pages 252 to 271 of vol. 17, No. 2 for February, 1929. A standard frequency or time system 26 is shown connected to the output of multi-vibrator circuit 22. This system may be any standard frequency system, such as one similar to the one about to be described or it may be one used to control the frequency of radio stations as described in U. S. patents to R. Bown 1,490,958, April 22, 1924 or L. Espenschied et al. 1,711,560, May 7, 1929 which are made part of this description. The output from multi-vibrator circuit 22 is also connected to multi-vibrator circuit 23 where the frequency of the current is further changed. A portion of the current then passes through still another vibrator circuit 24 which changes the frequency so that it is suitable for operating a frequency

integrating and recording device, such as clock 25. This clock 25 may be used to check the accuracy of the standard frequency obtained from the alternating current generator 21. A further portion of the current from multi-vibrator circuit 23 passes through transformer 27 over line 162. This line 162 may extend some distance from the constant frequency source or multi-vibrator 23 to terminals 51 of transformer 27. Condenser 28 and resistance 29 are connected in series with each other and to the output of the transformer 27. Since the same current must flow through both condenser 28 and resistance 29, the voltage drop across the condenser 28 will be ninety degrees out of phase with the voltage drop across resistance 29. These two voltage drops may be made equal by appropriate choice of the value of the capacity of condenser 28 and of the resistance 29. These two voltage drops are applied to the grids or input circuits of vacuum tubes 30 and 31, respectively. The outputs of these tubes are connected to coils 38 and 40, and 39 and 41 which are wound on ring 42. Ring 42 is preferably made of compressed dust of magnetic materials such as nickel-iron alloys but may be of any suitable magnetic material such as laminated iron, silicon steel, or hydrogenized iron. The two coils 38 and 40, as well as 39 and 41, are wound in opposite directions so as to produce a magnetic field diametrically across the ring. It should be noted that coils 39 and 41 are spaced ninety degrees around the ring from coils 38 and 40 so that when these coils are energized by the output currents from tubes 30 and 31 which are in phase quadrature, a rotating field is produced which rotates at a speed proportional to the input frequency from the standard frequency source 21 as changed by multi-vibrator circuits 22 and 23. Condensers 32 and 33 are connected in parallel with coils 38 and 40 and 39 and 41, to tune them to resonate at the impressed frequency and also to make minor adjustments in the relative phase between the two currents from tubes 30 and 31.

An armature 43 is mounted on shaft 76 and is located in the rotating magnetic field across the ring 42. Armature 43 is usually made of the same magnetic material as ring 42 but may be of any other suitable magnetic material. Armature 43 is rotated by motor 70 through gears 58 and 67 at any desired or specified speed of say ΔF revolutions per second. The pick-up coil or winding 44 on armature 43 will then have induced in it a current of a frequency equal to $F \pm \Delta F$, where F is the standard frequency and the sign depends upon the relative directions of rotation of armature 43 and the rotating magnetic field across the ring 42. The winding 44 on armature 43 is connected through slip rings 45 and 46 to the input circuit of tube 47 through terminals 50 where the current induced in winding 43 is amplified by tube 47 and is transmitted through the output transformer 48 to terminals 49. A portion of the current from terminal 49 then passes through another multi-vibrator circuit 52 which again changes its frequency so that it is suitable for operating small synchronous motors which in turn drive clock mechanisms. The clock 55 connected to bus 56 is supplied by the output current from multi-vibrator circuit 52. The time indicated by clock 55 may be periodically checked by time signals received by radio receiver 58 from antenna 57. It is to be understood, however, that this clock may be checked in any other convenient manner, such as observations from stars or by telegraph or telephone signals from the average

time as indicated by a group of observatories, such as furnished by the United States Government. In addition, a suitable recording and comparing device 59 such as described in U. S. patent to F. D. Urie 1,202,925, October 31, 1916 may be connected between buses 56 and radio receiver 58 to automatically compare and record the time signals as received with the frequency of the alternating current flowing in buses 56. Radio receiver 58 may also be used to compare the frequency of source 21 with time signals by means of clock 25 either visually or by any suitable automatic means provided clock 25 and receiver 58 are sufficiently close together. If this is not the case, a separate radio receiver 300 may be provided so that the time indicated by clock 25 may be compared with time signals.

Also connected to terminal 49 is an amplifier 53 which will amplify standard frequency current so that it may be transmitted to a distant multi-vibrator circuit 54 where its frequency will be altered suitably for operating a similar standard frequency or time system. It is to be understood that any of the multi-vibrators 22, 23, 24, 52, or 54 may be omitted in case it is not necessary to alter the frequency of the standard frequency source. In addition, amplifier 53 may be omitted or additional amplifiers connected in the line to multi-vibrator 54 depending upon the attenuation of this line.

Fig. 2—A shows an alternative arrangement for armature 43. Here windings 75 and 76 are wound upon a ring 74 which is mounted upon shaft 76 so that it may be rotated in a manner similar to that described for armature 43. Both this ring armature and the drum armature have been found to be suitable for obtaining a very uniform and regular phase change with the rotation of the armature. It has also been found that the frequency and phase change of the current in the pick-up coil is more uniform and regular when the air-gap between the armature and the ring is as short as possible.

It should also be noted that the quadrature voltage drops across condenser 28 and resistance 29 (see Fig. 2) are applied directly to the input circuits of tubes 30 and 31. This substantially eliminates the effects of stray capacities or couplings upon the phase relationship of these two quadrature voltages which tend to change the magnitude and also the relative phases of these two voltages. In addition, the vacuum tube 47 prevents changes in the load impedance or output current from materially affecting the phase and frequency of the voltage induced in the pick-up coil and thus the phase and frequency of the output voltage.

Referring again to Fig. 2, motor armature 70 and field 71 are connected through key 72 and contacts 64 to a source of power 73. A revolution counter 69 is also connected to shaft 76 and is employed to record the total number of revolutions made by shaft 76 and armature 43. Dial 60 is also connected to shaft 76 through suitable gears such as 67 and 66 and friction clutch 65. Dial 60 is provided with an indicator 61 and knob 62. Cam 63 rotates with dial 60 and controls contacts 64.

Dial 60 may be calibrated in any suitable unit, such as seconds, thousandths of a second, or cycles. Assume, for purposes of illustration, that dial 60 is calibrated in hundredths of a second. Assume further that when time signals are received from antenna 57 by radio receiver 58, clock 55 is 0.05 second fast. Then, some time before

the next set of time signals or during the following day or whenever desirable, dial 60 will be rotated in the direction of the arrow F so that indicator 61 will indicate 0.05 second. This will also rotate cam 63 which will cause it to close contacts 64. It should be noted that the rotation of disc 60 does not rotate armature 43 since it is connected to shaft 76 upon which armature 43 is mounted through friction clutch 65 which allows cam 63 and dial 60 to be rotated without rotating gears 66 and 67 and armature 43. Contacts 64, in closing, connect power from source 73 to key 72. Then, when it is desired to correct clock 55, as well as all the other electric clocks which are run by synchronous motors and are connected to the standard frequency system, key 72 is operated so as to close the F contacts. This completes the circuit to motor armature 70 and field 71 so that armature 43 will be rotated in a direction to cause a correction to the reading of clock 55 as well as the other electric clocks connected to the system. The speed of motor 70, as well as the gear ratio between motor 70 and shaft 76, is adjusted so that the adjustment in the frequency and phase of the current and thus the time indicated by clock 55 is made at any desired or specified rate.

The term "time signals" as used in the above example and this specification includes both single and the average or mean of a plurality of observations of suitable signals. In some cases it may be desirable to attempt to correct for slight random errors in the observations or time signals. This may be done by making the best possible estimate of the probable error of the observation or time signal based upon all previous time signals and other data. The observation or time signal may then be corrected and the frequency or clocks of the system adjusted in accordance with this corrected observation or time signal.

Bus-bar 56 extends from Fig. 2 to Fig. 3 where numerous forms of distribution systems are shown. For example, carrier equipment 82 is connected to bus-bar 56 and, in turn, to line 83 which may extend a considerable distance and include suitable amplifiers and other apparatus (not shown) to the carrier apparatus 84 located near clock system 85. In case of an unusually long line, as line 88, it may be desirable to provide phase adjusting apparatus such as disclosed in U. S. patents to H. A. Affel 1,450,966, April 10, 1923; H. Nyquist 1,615,911, February 1, 1927; and H. Nyquist 1,683,725 September 11, 1928 which are hereby made part of this description, and illustrated at 86 either before or after a carrier apparatus, such as 87, in order to compensate for phase changes occurring in line 88 due to temperature and general weather conditions. In this case, the standard frequency current is applied to numerous channels of a multi-channel carrier system in which one channel is terminated in carrier equipment illustrated at 89 and supplies clock system 90. Another channel terminates in carrier equipment 91 and supplies standard frequency to clock system 92, while a third channel is shown terminating in carrier equipment 93 and supplying clock system 94. In other cases it may be desirable to connect clock systems directly to bus-bar 56 over suitable lines, such as 97. Clock system 95 illustrates such a system connected to bus-bar 56 by line 97. In case the line becomes unusually long, it may be necessary to provide receiving amplifiers, as illustrated at 96 and 99, for clock systems 98 and 100. In case of ex-

tremely long lines, it may be desirable to provide a transmitting amplifier 78 connected to line 79 in addition to a receiving amplifier 80, for supplying a clock system 81. In addition, line 79 may pass through other suitable amplifiers and phase adjusting apparatus. It should be noted that transmitting amplifier 78 provides an additional safeguard in that it prevents any troubles occurring on line 79 from affecting the current supplied to any of the other lines connected to bus-bars 56. For this reason, it may be desirable to provide a transmitting amplifier for each of the lines and systems connected to bus-bars 56 so that any trouble or abnormal conditions arising on any of the lines will affect only the lines in trouble but will not affect the entire system. These amplifiers may be of any suitable type including both constant gain and constant output types of amplifiers and also feedback amplifiers such as described in a patent application of H. S. Black Serial No. 411,224, filed December 3, 1929 which issued as Patent 2,003,282 on June 4, 1935.

These clock systems 81, 85, 90, 92, 94, 98 and 100 may be of any type such as employed in schools, hotels, hospitals, public buildings, railroads, train dispatching, industrial organizations, telephone systems as described in U. S. patent to W. B. Prince 1,863,141, June 14, 1932, telegraph systems such as described in U. S. patent to T. A. McCann 1,940,764, December 26, 1933, or in clock and watch adjusting apparatus similar to that disclosed in a patent application of C. H. Fetter et al. Serial No. 673,882, filed June 1, 1933 which issued as Patent 2,037,161 on April 14, 1936. Both of these patents and the above application are hereby made part of this application.

Line 163 is also shown connected to bus-bars 56 and extends to a power house 101 which includes Fig. 4, as well as part of Fig. 3. Line 163 extends to a switchboard 110 at the power house. This switchboard is assumed to be a central switchboard for the entire power system from which various switching arrangements and load divisions in the power system are controlled. Located in this switchboard are clocks 103 and 104. Clock 103 is connected to line 163 and indicates the correct time while clock 104 is connected to the power system and indicates the time indicated by electric clocks connected to the power system.

A group of variable phase shifting or adjusting devices 105, 106, 107, 108, and 109 are located in or near control board 110 and are controlled from this board. These phase shifters or adjusters are connected to line 163 and may be any suitable form as, for example, somewhat similar to the phase shifting device shown in Fig. 2. One of these phase shifting devices is provided for each generator or power house, the load of which it is desired to control from the central point. From these phase shifting devices lines extend to the various power houses and generators of the system to be controlled from this central power house or control board. For example, line 213 from phase shifter 105 extends to an outlying power system 116 through amplifier 115. This outlying power system 116 may, at times, be connected to the power system controlled from board 110 or may be entirely independent of the power system to which power house 101 is connected. Lines 118 and 119 from the variable phase shifters 106 and 107 extend to the control apparatus associated with generators in the power house 101 and illustrated within the

broken lines 157 and 156 (Fig. 4). This control apparatus may be of any suitable form such as apparatus for comparing the times indicated by two clocks similar to 103 and 104, one of which is run from the power system and the other from the standard frequency system and then controlling the frequency of the power system in accordance with the difference in the two clocks. Two forms of apparatus for doing this are shown in U. S. Patents 1,310,372 granted on July 15, 1919 to A. F. Poole and 1,505,925 granted on August 19, 1924 to H. E. Warren. However, the preferred manner of regulating the frequency of the power system from the standard frequency current is shown in Fig. 4.

Referring now to Fig. 4, line 118 from phase shifter 106 is connected to an improved modulator similar to the one disclosed in U. S. patent to W. A. Marrison, 1,762,725, June 10, 1930. The modulator shown in Fig. 4 does not require any phase splitting device as shown in the patent. Line 118 from the phase adjusting arrangement 106 is connected to the primary sides of three transformers 120, 121 and 122. The secondaries of these transformers are balanced and connected to tubes 123 and 124, 125 and 126, and 127 and 128, respectively. These tubes may be the usual high vacuum tubes or they may be of the gas or "thyatron" type depending largely on amount of torque required for the polyphase control motor, since both types function equally well. The gas or "thyatron" type, however, is usually employed where more output power is required. The plate power for these tubes is supplied from a three-phase power supply system through transformer bank 137. This power is supplied from the power system or by alternator 136, the frequency and phase of which it is desired to control. This plate supply power for these tubes is connected to the output circuit of the tubes through windings 129, 130 and 131 of motor 132. If the phase of both generator 136 and the standard frequency from the variable phase shifter 106 over line 118 remains constant, motor 132 will remain stationary. However, should the phase of either system vary, motor 132 will rotate in accordance with the variations. Motor 132 is connected to the governor 134 and may change the governor limits or in any other way control the prime mover 135 driving generator 136. Governor 134 may be provided with the usual connections, illustrated by lines 161, to the power system for compensating for load variations and other usual disturbances so that less control will be required by motor 132 and thus insure a more constant frequency. A feature of this modulating and controlling arrangement is that in case some trouble occurs to the line or apparatus supplying the standard frequency current so that this current is interrupted, motor 132 will remain in substantially its position at the time of the trouble and thus maintain the power frequency or the governor limits at the best known values.

Line 119 from variable phase shifter 107 is connected in a similar manner to the generator and associated apparatus illustrated within broken line 156. As pointed out above, should the frequency of this generator vary appreciably from that of the standard frequency, the control motor is actuated so as to correct the frequency of this generator. By adjusting the relative phases of the standard frequency current supplied to these two generators shown within broken lines 156 and 157, the relative load supplied by each generator may be readily controlled since motor 274

associated with generator and control apparatus 156, for example, is actuated by the relative phase and frequency of the standard frequency supplied over line 119 and that of the power system frequency. The same applies to generator shown within the broken line 157 so that if the standard frequency current supplied to these two control circuits varies in phase, the associated motor will cause a corresponding change in the governors controlling the two generators so that the generators will supply the desired amounts of power. These generators are connected through a transformer bank 140 to a power transmission line 141.

The output from variable phase shifting or adjusting devices 108 and 109 pass through carrier equipment 111 and 113 and through the power line carrier coupling equipment 112 and 114 which are, in turn, connected to power line 141. This carrier equipment 111 and 113 changes the frequency of the standard frequency current so that it will pass over different channels of the carrier equipment.

Fig. 5 shows power switching stations 142 and 146 to which are connected load centers, such as 144, by means of lines 143 and 275. These load centers contain clock systems, such as 146, which are preferably run by synchronous motors from the power system. However, it should be understood that in case it is so desired, a clock system may be run from the carrier current supplied over the power system. A generating and switching station is also shown at 145 connected to another load. This generator equipment may be similar to that shown in Fig. 4 or 6 or may be controlled in any other suitable manner.

Referring now to Fig. 6, the operation of an outlying connected power station will be described, as well as the manner in which it is controlled from the central station of switchboard 110. Here, carrier equipment 148 is coupled through power line coupling equipment 147 to the power system 141. Assume that the carrier equipment 148 selects the carrier current channel controlled by carrier current equipment 111 of Fig. 3 and converts the carrier current received from this channel into a suitable low frequency current, the phase of which is controlled from 108. A secondary frequency standard source 149 may be connected and controlled by this standard frequency received over the line. U. S. patents to H. Nyquist, 1,684,455, September 18, 1928; H. A. Affel, 1,740,491, December 24, 1929; and W. A. Marrison, 1,931,873, October 24, 1933, show suitable methods of controlling the frequency of the secondary source of standard frequency current and are hereby made part of this description. This secondary source is provided to control the generators at this power house in case some trouble occurs in the carrier equipment or in the power line supplying the carrier current to this station which prevents the reception of the control current. It is to be understood, however, that this secondary source may be omitted wherever it is not required without affecting the operation of the system. If the central control board 110 of the power system is some distance from the source of standard frequency, it may be desirable to provide a secondary standard frequency source similar to 149 at this central control board. Such a source might also be employed at each major or frequency control station of the power system.

The standard frequency current also supplies current for operating clock 150 (see Fig. 6) which is located adjacent clock 151. Clock 151 is sup-

plied from transformer 152 and the power bus 153 of the station. Variable phase shifting or adjusting devices 158 and 159 are provided for each of the generators shown within the broken lines 154 and 155 so that the loads may be divided between these generators in any suitable manner. The output from these generators is connected to the power transmission line through transformer bank 160. These generators are controlled in a manner similar to that described for those shown in Fig. 4 so that any change in the phase of the constant frequency current will cause a corresponding change in the load supplied to the power system by these generators. In case it is desired to control the load supplied to the system by the outlying power house shown in Fig. 6 from the central switchboard 110, all that is necessary is that the phase of the constant frequency current transmitted to the carrier system be adjusted by the variable phase adjuster 108. Thus, it is possible to control the load on each of the power generators of a system as well as the exchange of power between various power generating stations. It is to be understood that the other usual control and signaling apparatus is also located in switchboard 110 so that the operator may know and have all the necessary information to control the system. Since this additional equipment forms no part of the present invention, it has not been shown or described but it is understood that it will be provided when necessary.

Fig. 7 shows an alternative arrangement for shifting the phase of the standard frequency current which is suitable for standard frequency currents of higher frequency than that shown in Fig. 2. The arrangement shown in Fig. 2 is suitable for shifting the phase of currents up to say 100 kilocycles per second while that shown in Fig. 7 is more suitable for shifting the phase of a standard frequency current having a frequency above 100 kilocycles. Here, coil 164 is connected to the source of standard frequency current supplied to terminals 51. Coil 164 is inductively coupled to coils 165 and 166. Coil 165 is tuned by means of condenser 167 so that the combination resonates at a frequency slightly below the standard frequency current, while coil 166 is tuned by means of condenser 168 so that this combination resonates at a frequency slightly above the standard frequency current so that the voltages across coils 165 and 166 are substantially ninety degrees out of phase with each other. These voltages are applied to the grid or input circuits of tubes 169 and 170. Tubes 169 and 170 are provided, as in Fig. 2, to reduce the effects of stray fields upon these quadrature currents. The outputs of these tubes 169 and 170 are connected to coils 173, 175 and 174, 176, respectively. Condensers 171 and 172 are also connected to the output circuits of the tubes 169 and 170 and are used to resonate the coils 173, 175 and 174, 176, as well as make minor adjustments in the phase of the output currents supplied to these coils so that they will be substantially in phase quadrature. These coils 173, 175 and 174, 176 have their axes at right angles to each other so that they will produce a rotating magnetic field which rotates at the speed of the standard frequency when supplied by the current from tubes 169 and 170.

Coil 177 is mounted on shaft 76 and connected to slip rings 45 and 46 which in turn are connected to the input circuit of tube 47. In this case a resistance 178 is provided in series with the input circuit in order to further reduce the effect of the impedance of the input circuit of the

tube 47 upon the phase of the current induced in coil 177. Coil 177 is mounted on shaft 76 so that it rotates in the center of the field produced by coils 173, 175 and 174, 176. If this coil 177 is rotated ΔF revolutions per second as before it will then have induced in it a voltage having a frequency of $F \pm \Delta F$ where F is the frequency of the standard frequency current.

The phase regulating device shown in Fig. 8 is similar to that described in a patent application of L. A. Meacham Serial No. 686,352 filed August 23, 1933 and issued as Patent No. 2,004,613 on June 11, 1935 and operates in a slightly different manner than that described for Fig. 2. Here the standard frequency is supplied to terminals 51 as before. The primary windings of transformers 181 and 182 are connected in series with each other and to terminals 51. Each of the primary windings has connected in parallel with it a phase adjusting network such as 179 and 18. The secondary winding of transformer 181 is connected to the stationary condenser plates 183 and 184, while the secondary of transformer 182 is connected to the stationary condenser plates 186 and 187. These condensers are similar to those used in tuning radio receivers. However, the rotary plates are shaped as described in a patent application of L. A. Meacham, Serial No. 686,352, filed August 23, 1933 which issued as Patent 2,004,613 on June 11, 1935. Only one set of rotary plates 185 is provided for the stationary plates 183 and 184 and a second set of similar rotary plates 188 is provided for the stationary plates 186 and 187. These sets of rotor plates are mounted on shaft 190 at right angles to each other and are connected together and to transformer 189. Transformer 189 has its secondary connected to terminals 50 and to the input circuit of vacuum tube 47 the output of which is connected through the output transformer 48 to terminals 49. As in Figs. 2 and 7, tube 47 is provided to prevent the output or load impedance from affecting the output frequency. Condensers 215, 216, 217 and 218 are connected in parallel with stationary plates 183, 184, 186 and 187 and are used to adjust for any irregularities and differences in the capacities of these plates. It may not be necessary to provide all of these condensers, instead only one or two may be necessary in parallel with those plates which have the least amount of capacity.

Shaft 193 is rotated through gears 191 and 192 which in turn are rotated by wheel 193. Wheel 193 is rotated by means of disc 194 which rests on top of it. As disc 194 rotates, it rotates wheel 193 due to the friction between this wheel and the disc. Wheel 194 is rotated by pin 195 which is attached to shaft 197. Disc 194 is arranged so that it is free to slide up and down along shaft 197 so that it will always press against wheel 193 with a force sufficient to provide friction between it and wheel 193 to rotate wheel 193. Shaft 197 is rotated through gears 198 and 199 and shaft 200 by motor 201. Motor 201 is mounted on springs 202 which in turn are mounted on a carriage 207. Carriage 207 is supported by means of screw 204 which is mounted in members 205 and 206. Screw 204 is rotated by knob 240 through gears 209 and 208. Attached to gear 209 are gears 211 and 212 which rotate counters 213 and 214. These counters are used to indicate the position of motor 201. By rotating knob 210 and screw 204, motor 201 is caused to move back and forth along screw 204. This causes disc 194 also to move past wheel

193 and thus change the relative rates of rotation of disc 194 and wheel 193. Screw 204 is long enough to move disc 194 so that wheel 193 can make contact with disc 194 at either edge or anywhere in between so that not only may the relative rates of rotation of wheel 193 and disc 194 be varied, but also the relative directions of rotation. Thus, as shown, with wheel 193 to the right of shaft 197, it will rotate in one direction whereas if it is to the left of shaft 197 it will rotate in the opposite direction with shaft 197 rotating in the same direction. Motor 201 is provided with a centrifugal contact 219 which is connected to alarm circuit 220. These contacts are provided to give an alarm in case motor 201 stops for any reason. Motor 201 is preferably a synchronous motor which may be supplied with power either from a regulated power system or from the standard frequency current supply system.

The operation of this system is somewhat different from that described for Fig. 2. Assume that the phase regulating arrangement shown in Fig. 8 is connected in place of the one shown in Fig. 2 and that the clock 55 is 0.05 of a second fast when compared with time signals or other observations. In this case knob 210 will be turned so that registers 213 and 214 will indicate that during the next twenty-four hours, motor 201 will turn shaft 190 through gears 191, 192, and wheel 193 and disc 194 so as to correct for this error. It may be set so as to maintain the frequency as nearly correct as possible in which case at the end of a twenty-four hour period or any other suitable period the clock 55 will still read 0.05 of a second slow or it may be set so that at the end of this period clock 55 will read the exact time. The manner in which the rotation of the movable condenser plates 185 and 188 with shaft 190 advances or retards the phase of the standard frequency is described in detail in a patent application of L. A. Meacham, Serial No. 686,352, filed August 23, 1933, and issued as Patent 2,004,613 on June 11, 1935, which application and patent is hereby made part of this specification.

It should be noted that with the regulating device shown in Fig. 2 the integrated phase of the standard frequency current or the time indicated by the clocks operated by this current is periodically adjusted or regulated at a uniform rate while with the device shown in Fig. 8 the phase of the standard frequency current is continuously and uniformly adjusted or regulated in accordance with the best available past and present observations of some periodically recurring natural phenomenon such as time signals. This continuous and uniform adjusting of the phase of the standard frequency current amounts to a small change in the frequency since the phase of an alternating current cannot be changed without changing the frequency and the frequency cannot be changed without changing the phase. However, since the correction or change made to the standard frequency is very small it has been called a phase change in this specification and appended claims. In the case of the power frequency both the terms "frequency" and "phase" are employed since the usual variations of frequency are much greater.

In some cases such as those in which the frequency of the standard current is of major importance, it may be necessary or desirable to employ a system operated as described for Fig. 8 while in other cases, such as those in which

the integrated phase or time indicated by clocks operated by the standard frequency is of major importance a system such as described in Fig. 2 is preferable. Sometimes it may be desirable to employ both methods, that is, pass the standard frequency currents through a frequency adjusting mechanism in accordance with Fig. 8 and then through a time adjusting mechanism in accordance with Fig. 2. In case it is desired to have the standard frequency current adjusted in accordance with each method, it may be desirable to employ an arrangement in accordance with Fig. 8 in the standard frequency or time system illustrated in diagrammatic form at 26 in Fig. 2 and at the same time employ the phase regulating system shown in Fig. 2 for the other parts of the system. In this case the system shown at 26 may be used to regulate watches, clocks, radio stations and the like while the system shown in Figs. 2 to 6 may be used to provide a standard time service. In addition, it is to be noted that systems or apparatus shown in Figs. 2, 7 and 8 may be operated in either manner. That is, to continuously regulate the phase or to intermittently regulate the phase of the standard frequency current.

Fig. 9 shows a modulator employing relays instead of tubes which may be used in place of the modulator shown in Fig. 4 for comparing the standard frequency with the power frequency. Here relays 220, 221 and 222 are connected through line 219 to the source of phase adjusted standard frequency current. These relays 220, 221 and 222 are preferably polar relays and follow the standard frequency. That is, they close one contact during one-half of the cycle and other contact during the other half of the cycle. The contacts of these relays are connected to the three-phase power from the generator through transformer bank 230, each phase of the power current being connected to the contacts of one of the relays through copper-oxide rectifiers and to one of the windings of motor 237 so as to produce a rotating field and rotate armature 237 of the motor in case there is any phase or frequency variation between the standard frequency and the power frequency. The rotation of this motor in turn rotates shaft 238 which is connected to governor 239. Governor 239 may be also controlled by the load on generator 251 by leads 240. Governor 239 controls the prime mover 250 which drives the generator 251 which supplies power to the power system through switch 287.

Fig. 10 shows a modulator suitable for use in comparing a standard frequency with a single phase power system and controlling a single phase generator in accordance with the phase and frequency differences of the two systems. The primaries of transformers 253 and 255 are connected to a standard frequency source over line 252. The secondary windings of these transformers are tuned by means of condensers 254 and 256 so that the voltages across the secondaries will be ninety degrees out of phase with each other. The voltages are then applied to tubes 259, 260, 261 and 262. The output circuits of these tubes are connected to windings 263 and 264 of motor 265 in such a manner as to produce a rotating magnetic field in accordance with the difference between the power frequency and the standard frequency. It should be noted that both the filament and plate voltages for these tubes are supplied by means of transformers 257 and 258 which are connected to the power system through transformers 272. Motor 265 in turn ro-

tates shaft 266 which controls governors 267 in accordance with the difference in the power frequency and the standard frequency. This governor may likewise be controlled by the load supplied by generator 271 over leads 269. The governor in turn controls the prime mover 268 which drives generator 271 through shaft 270 so that the power frequency will be regulated in accordance with the standard frequency. Tubes 259, 260, 261 and 262 may be of the high vacuum type or in case more power is required to rotate the motor 265 they may be of the gas-filled, discharge, or "thyatron" type of tube. Either type of tube functions equally well in this circuit and since the losses of the gas-filled type are less, they probably would be preferred.

In some cases the power available to operate the motor from the modulator may be insufficient in which case it will be necessary to amplify the torque of these motors. Fig. 11 shows one method of doing this. Here motor 132 rotates shaft 133 which is coupled to an insulated coupling 273 which in turn rotates the contact arm 276. Contact is made from arm 276 by means of slip ring and brush 274. The shaft 286 from the governor or throttle of the prime mover carries a gear 280 and slip rings 284 and 285. Mounted on this gear 280 are two contacts 275 and 277 which are connected through the slip rings 30 to motor 283 so that when motor 132 rotates contact arm 276 so that it makes contact with contact member 275, motor 283 will rotate shaft 282 and gear 281 in such a direction as to rotate gear 280 and contact 275 mounted thereon away from contact 276. The power of motor 283 may be as large as necessary and the speed may be reduced through gears 281 and 280 so that the torque available to turn shaft 286 is increased.

The object of the above description of a specific standard frequency system in which the phase of the standard frequency is regulated and several specific ways illustrate the manner of employing this standard frequency for certain specific uses is to illustrate this invention, but is not to limit or restrict its scope as defined in the following claims.

What is claimed is:

1. A standard frequency alternating current system comprising a source of standard frequency alternating current, and means operating independently of said source connected to said standard frequency current source for continuously and uniformly shifting the phase of said standard frequency current source.

2. A standard frequency alternating current system comprising a source of standard frequency alternating current, and means operating independently of said source connected to said source for intermittently regulating the phase of said standard frequency alternating current at a uniform rate.

3. A standard frequency system comprising a primary standard frequency source, a distributing network connected to said source, secondary standard frequency sources connected to said network, means for controlling said secondary standard frequency sources from said primary standard frequency source, and devices actuated by standard frequency current connected to said secondary standard frequency sources.

4. In a constant frequency system, means for shifting the phase of a constant frequency current any given phase angle at a uniform rate which comprises an input and an output circuit, means connected to said input circuit for secur-

ing polyphase current from said input circuit, a space discharge device connected to said means for each phase of said polyphase circuit, means connected to said space discharge devices for securing a rotating magnetic field from said polyphase currents, and a pick-up coil connected to said output circuit, and means for rotating said pick-up coil in said rotating magnetic field whereby the phase of the output current is varied in accordance with the rotation of said pick-up coil.

5. Means for continuously shifting the phase of an alternating current comprising an input and an output circuit, a condenser and a resistance connected in series and to said input circuit for securing voltages in phase quadrature, two space discharge devices having their input circuits connected to said resistance and condenser, a compressed permalloy dust ring having two sets of windings wound thereon which produce two magnetic fields across said ring which are at right angles to each other, said windings being connected to said space discharge devices for producing a rotating magnetic field when energized from said space discharge devices, a pick-up coil wound on a compressed permalloy dust core located in said magnetic field, means for continuously rotating said pick-up coil for continuously shifting the phase of the current induced therein, a third space discharge device having its input connected to said pick-up coil and its output connected to said output circuit for substantially eliminating the effects of changes in the output circuit upon the frequency and phase of the current induced in the pick-up coil.

6. A constant frequency system comprising a source of constant frequency current, a phase regulator connected to said source, and time indicating devices connected to said phase regulator.

7. A distributing system comprising a plurality of synchronous electrical clocks, an electrical current distributing network to which said clocks are connected, phase regulating means connected in said network for compensating for changes of said networks, a source of standard frequency current connected to said network, a source of time signals, means for comparing the time indicated by said clocks with standard time signals, and means for adjusting the phase of current from said standard frequency source whereby said clocks can be simultaneously adjusted to indicate the correct time.

8. A system which comprises in combination a standard frequency system having a source of alternating current the frequency of which is substantially constant, a phase regulating device for regulating the phase of the alternating current received from said source and a distributing network connected to said device, and a plurality of clock systems connected to said network and controlled by said standard frequency.

9. A system, in accordance with claim 8, in which certain of said electrical clock systems are used to regulate and control the frequency of a power supply system comprising means for comparing the time indicated by the clocks of said system with the time indicated by electrical clocks operated from said power system, and means for controlling said power frequency in accordance with the difference in the time indicated by said clocks.

10. In combination, a three-phase alternating current distributing system, a source of standard frequency current, a modulating device connected between each phase of said distributing system

and said standard frequency current, and means connected to said modulators for controlling the frequency of said distributing system.

11. Means for regulating the frequency of a three-phase alternating current generator from a standard frequency current which comprises a modulating arrangement for modulating each phase of said three-phase alternating current, each of said modulating arrangements including at least one space discharge device, and means controlled by said modulating arrangements for controlling the frequency of the current generated by said generator.

12. In a three-phase alternating current power system, a three-phase generator, a source of standard frequency current, a modulating arrangement which comprises at least one gas-filled tube and circuit arrangement for modulating each phase of said three-phase alternating current with said standard frequency current, and means for controlling the frequency of said generator from said modulating arrangements.

13. A polyphase alternating current network comprising a plurality of geographically separated alternating current generators connected to said network for supplying electrical power thereto, a plurality of electrical energy consuming devices connected to said network, a source of standard frequency current, means for transmitting said standard frequency current to said geographically separated generators, and means for controlling the frequency and phase of the current generated by said generators in accordance with said standard frequency current.

14. A polyphase alternating current supply network in accordance with claim 11, comprising means for transmitting said standard frequency current to said geographically separated generators with different relative phases whereby the division of load between said geographically separated alternating current generators may be controlled from said central point.

15. An alternating current supply network in accordance with claim 11, in which a means for transmitting said standard frequency current to the geographically separated alternating current generators comprises carrier transmitting equipment operating over the supply network of said system.

16. A system for controlling the frequency and phase of a power system which comprises a source of constant frequency current, means for regulating the phase of said constant frequency current, and means for controlling the frequency and phase of said power system from said phase regulated constant frequency current.

17. In combination an alternating current polyphase distributing network comprising a plurality of geographically separated alternating current generators connected to said network for supplying electrical power thereto, a plurality of electrical energy consuming devices connected to said network, a plurality of electric clocks driven by synchronous motors also connected to said networks for indicating time, a source of standard frequency current, means for comparing said standard frequency current with time signals, a phase regulating device connected to said source for regulating the phase of said standard frequency current, means for transmitting said phase regulated standard frequency current to said geographically separated generators, means located at each of said generators for comparing the current of each phase of said polyphase currents generated thereby with said

phase regulated standard frequency current and means for controlling the frequency and regulating phase of said generators in accordance with said phase comparing means.

18. In combination an alternating current network, a plurality of alternating current generators connected thereto for generating electric power, a plurality of alternating current electrical energy consuming devices connected to said network, a plurality of electrical clocks driven by synchronous motors also connected to said network, a source of standard frequency current, means for comparing the frequency of said power system with said standard frequency current, means for controlling the frequency of said generators from said comparing means, means for checking the phase of said standard frequency current with observations of some periodically recurring phenomenon, and means for adjusting the phase of said standard frequency current at a specified rate.

19. A standard frequency alternating current system comprising a source of alternating current the frequency of which is substantially constant, a phase regulating device for regulating the phase of the current transmitted through it, and means for transmitting said constant frequency current through said phase regulating device.

20. A distributing system comprising a source of alternating current the frequency of which is substantially constant, a plurality of electric clocks run by synchronous motors connected to said source of constant frequency current, characterized in this that means are connected between said source and said plurality of clock motors for regulating the phase of said constant frequency current supplied to said clock motors.

21. A device for adjusting the phase of an alternating current at a uniform rate comprising an input and an output circuit, means connected to said input circuit for securing two phase currents therefrom, a space discharge device individual to each phase of said two-phase current connected to said means, means connected to said space discharge devices for securing a rotating magnetic field from said two-phase current, and a pick-up coil connected in said output circuit, and means for rotating said pick-up coil at a uniform rate in said magnetic field whereby the phase of the output current is varied at a uniform rate in accordance with the rotation of said pick-up coil.

22. A device for continuously adjusting the phase of an alternating current comprising an input circuit, an output circuit, means connected in said input circuit for securing polyphase current therefrom, a space discharge device connected to said means individual to each phase of said polyphase current, a ring of magnetic material, a winding wound thereupon for each phase of said polyphase current, and means for connecting said space discharge devices to said windings for producing a rotating magnetic field across said ring by said polyphase current from said space discharge devices, a pick-up coil wound upon an armature of magnetic material, an additional space discharge device connecting said pick-up coil to said output circuit, and means for uniformly rotating said armature in said rotating magnetic field whereby the phase of the output current is uniformly adjusted.

23. An alternating current distribution network comprising a plurality of generating stations, means for controlling the frequency of

said alternating current network which comprises a source of alternating current the frequency of which is substantially constant, a source of time signals, means for comparing said
5 source of constant frequency alternating current with said time signal, means for adjusting the phase of said constant frequency alternating current at a uniform and specified rate, means for
10 distributing said phase adjusted constant frequency current to said generating stations, means for comparing the phase adjusted constant frequency current and the alternating current generated at each of said generating stations, and
15 means for controlling the current generated by said stations in accordance with the relative phases of said current generated by said stations and said phase adjusted current.

24. Means for controlling the frequency of the current in an alternating current distributing
20 network which comprises a source of constant frequency alternating current, said source having an

oscillator controlled by a mechanical vibrating element, a source of time signals, means for comparing said constant frequency current with time signals, means for adjusting the phase of said
5 constant frequency current at a uniform rate, a plurality of alternating current generators connected to said distributing network, a plurality of governor controlled prime movers driving said
10 alternators, means for distributing said phase corrected constant frequency current adjacent to said alternators, means for comparing, the frequency and phase of said phase adjusted constant frequency current with the frequency and
15 phase of the current generated by said alternators, and means for controlling the governors of said prime movers which drive said alternators in accordance with the relative phases of said phase
adjusted constant frequency current and said
alternating current generated by said alternators.

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