Dec. 11, 1956 D. E. ABELL 2,774,030

THREE-PHASE LOW FREQUENCY GENERATOR

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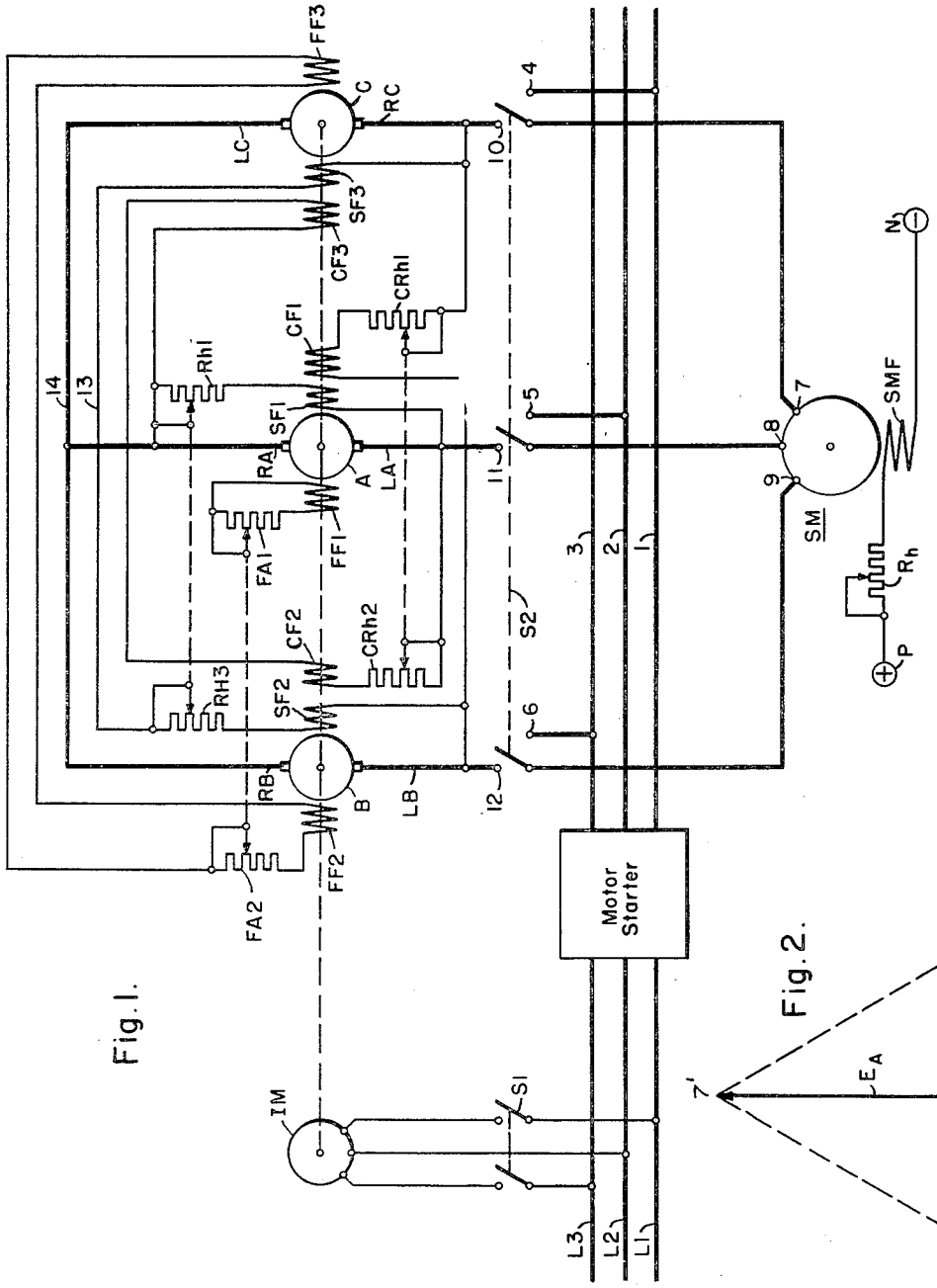


Fig. 1.

Fig. 2.

WITNESSES

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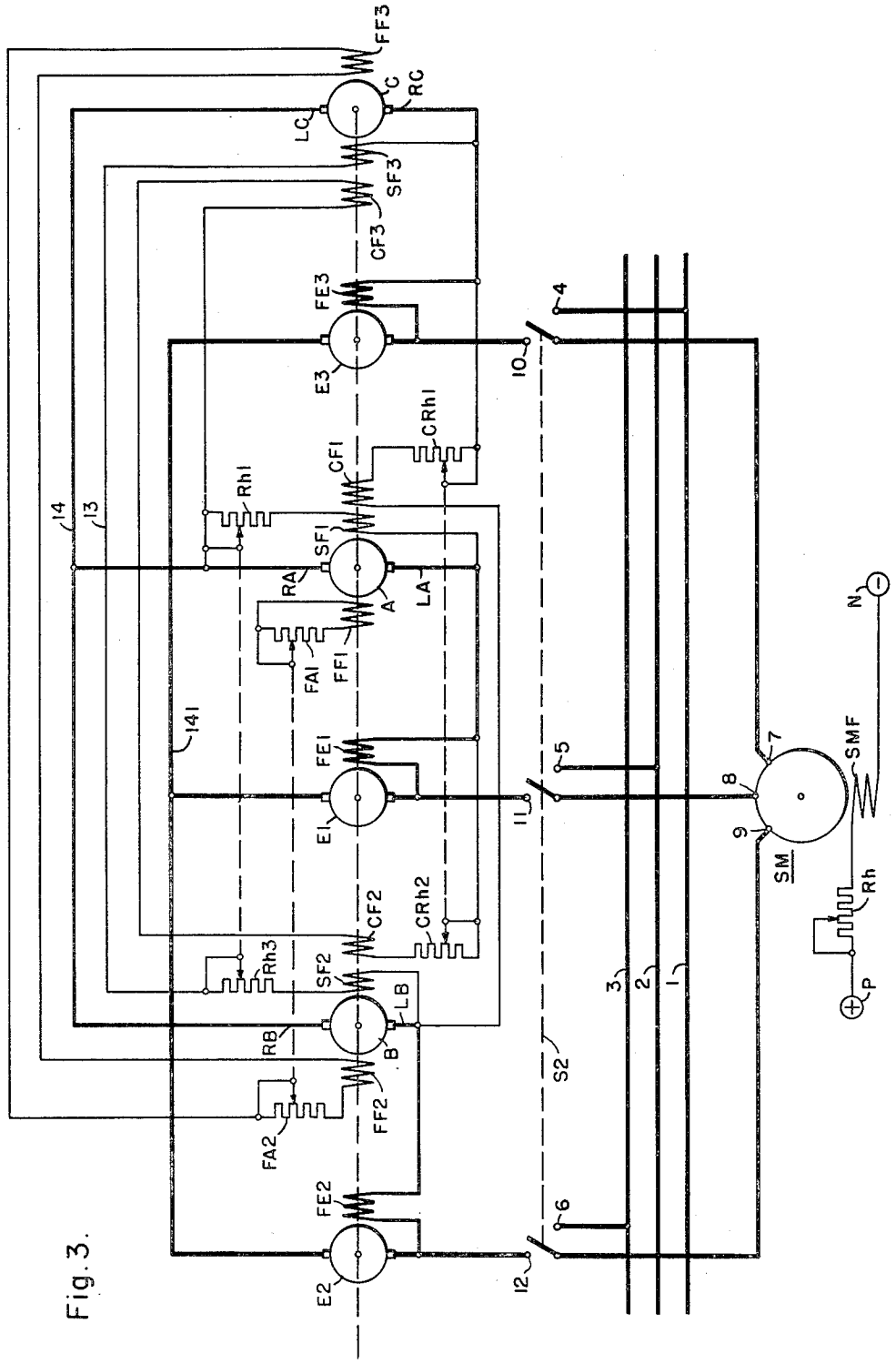


Fig. 3.

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2,774,030

THREE-PHASE LOW FREQUENCY GENERATOR

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Application May 10, 1955, Serial No. 507,193

11 Claims. (Cl. 322—61)

My invention relates to electric systems of control for producing low frequency alternating currents to effect inching operation of alternating current motors, or to supply any load requiring a low frequency supply.

In a number of industrial applications, an electric motor is called upon for one portion of its operating cycle to drive its load at full speed, and for another portion of its operating cycle to drive its load at a speed that is a small fraction of the full speed.

Typical examples of such operating requirements may be found in steel mills, rubber mills, paper mills, and sugar mills. In a rubber mill, as well as in a paper mill or steel mill, the threading speed or some other adjusting speed, may be a relatively very low inching speed. In sugar mills the centrifuges are, for the extraction of the liquid, operated at a high speed, but when the sugar is to be "plowed" from the centrifuge, the operating speed of the centrifuge must be a small fraction of the full speed.

There are a number of systems of control for this purpose known in the art, but the prior systems have not always been entirely satisfactory.

A broad object of my invention is the provision of electric apparatus for supplying low frequency alternating current to a load circuit.

A more specific object of my invention is the provision of a system of control for altering the frequency of the alternating current to be supplied to an alternating current motor to thus alter its speed from a selected substantially normal operating speed to a low inching speed.

Another specific object of my invention is the provision of generating apparatus in combination with control apparatus for selectively connecting normal frequency alternating current supply means and direct current generating means to load leads to supply the leads selectively either with normal frequency alternating current energy or with low frequency alternating current energy from the direct current generating means.

The objects recited are merely illustrative. Other objects and advantages will become more apparent from a study of the following specification and the accompanying drawing, in which:

Figure 1 is a diagrammatic showing of my system of control;

Fig. 2 shows a vector diagram of aid in explaining the merits of my invention; and

Fig. 3 is a diagrammatic showing of a modification of my invention.

The diagrammatic showing of my invention in Fig. 1 illustrates a simple control system providing an accurate method for obtaining a low frequency alternating current supply voltage for the purpose of providing an inching speed for the synchronous motor SM. This motor has a field winding SMF energized from the direct current terminals P and N through the adjusting rheostat R*h*.

Leads L1, L2, and L3 are normally energized with alternating current of a selected normal frequency and a selected normal voltage. For the application had in mind,

which usually involves a relatively large synchronous motor, the selected normal frequency may be in the range of 25 to 66⅔ cycles per second and the selected normal supply voltage may be in the range from 2300 to 13,800 volts.

During normal full speed operation, leads **1**, **2** and **3** are energized through the motor starter, and switch **S2** is operated to close the contacts **4**, **5**, and **6** to energize the motor terminals **7**, **8**, and **9**.

When the synchronous motor is to be operated at inching speed, switch **S1** is closed to energize the induction motor IM to drive the three multi-field direct current generators, or exciters, A, B, and C. Switch **S2** is operated, when the generators are up to speed, to its counter-clockwise position to close contacts **10**, **11**, and **12**.

Each of the generators has a control field winding. The control field winding CF1 for generator A is a differential field winding and is connected across armature terminals LB and RC through the control rheostat CR*h*1 and is, thus, energized as a function of the sum of the voltages appearing at the armature terminals LB and RB, and RC and LC of the generators B and C, respectively.

The control field windings CF2 and CF3 of generators B and C, respectively, are cumulative field windings and are connected across the armature terminals LA and RA of the generator A through the control rheostat CR*h*2.

Since the adjustments of control excitations, after some individual excitation adjustments, may need to be made simultaneously and proportionally, the rheostats CR*h*1 and CR*h*2 are preferably ganged as shown.

Each exciter is provided with a second field winding. These second field windings are the frequency control windings. The frequency control winding FF1 of exciter A is connected upon itself through the rheostat FA1. The frequency control windings FF2 and FF3 are connected in a loop circuit including the rheostat FA2. Since the frequency adjustment may need to be made simultaneously and in a correlated manner, the rheostats FA1 and FA2 are ganged as shown.

The armatures of the generators are connected in a T network, or Scott connection. The showing in Fig. 1 and the circuitry above discussed show that the output of the direct current generator A is fed into the series connected field windings CF2 and CF3 and is amplified by the armatures of the generators B and C. For purposes of oscillation, the output of generators B and C in series is fed back into the field winding CF1 of generator A in a degenerative sense, or manner. For this purpose, generators B and C act as one machine which is center-tapped. Lead **14** constitutes this center-tapped connection.

The system thus far described will not oscillate but by the addition of a third field winding to each machine, namely, the shunt self-energizing field windings, the damping effect of the two-delay regulator is cancelled and the system will effectively oscillate.

For the generator A, the self-energizing field winding SF1 is connected to the armature terminals LA and RA of generator A through the control rheostat R*h*1. For the generators B and C, the self-energizing field windings S*f*2 and S*f*3 are connected in series through control rheostat R*h*3 and lead **13** across the opposite armature terminals LB and RC of the generators B and C, respectively. The rheostats R*h*1 and R*h*3 are preferably ganged as shown, so that simultaneous adjustments of the resistances of the field circuits for the field windings S*f*1, S*f*2 and S*f*3 may be made.

The generators are shunt-tuned. Theoretically, each exciter need only be 100% tuned. However, in practice, each exciter may be somewhat over-tuned. This insures driving the exciter voltages up so that the exciters each

operate into the knees of their exciter saturation curves. Thus, changes in amplitude and frequency due to temperature changes are minimized. This does, of course, produce a small amount of distortion in the wave form, but this is not critical.

The three exciters are picked so that they have substantially the same frame size. The gains of the field windings are so adjusted that the voltage of generator A is 86.6% of the total voltage of the generators B and C connected in series. With this difference in voltage output and the T network connection of the generators, it is apparent that the three-phase conversion may be made without the use of additional machines, as shown in the copending application of Donald E. Abell and Henry J. Oakes, Serial No. 458,212, filed September 24, 1954, now U. S. Patent No. 2,743,411 and entitled "Three-Phase Low Frequency Generator." My present invention is thus an improvement over the electric system disclosed in the just mentioned copending application.

From the arrangement described and the circuitry shown, it is apparent that each exciter thus has a voltage output that follows essentially a sine wave and is of the same frequency and amplitude relationships and phase dispositions to supply three-phase alternating current to the load; namely, the terminals 7, 8, and 9 of the synchronous motor SM.

Fig. 2 shows how the output of the voltage vectors E_A, E_B and Ec at points 7', 8', and 9', corresponding to the terminals 7, 8 and 9 of the synchronous motor, is a typical three-phase output.

In the modification shown in Fig. 3, the generators A, B and C have their respective field windings connected in exactly the same relation as shown in Fig. 1. It is thus not necessary to repeat the description of the function of these generators and to facilitate the understanding of the subject matter shown in Fig. 3, I have used the same reference characters as have been used in Fig. 1, except where a distinct difference between the two modifications is apparent.

There are several distinct and important differences between the showing in Fig. 3 and the showing in Fig. 1. Before going into the detail of the circuitry, a brief discussion of the purposes of the modification shown in Fig. 3 may be important.

Frequently exciters are used as amplifiers for low frequency systems. The exciter field windings are supplied by either a rotating rheostat or by oscillator circuits made up of amplifying generators or exciters. For large applications, that is applications where say the load as the synchronous motor SM is of a relatively large capacity, the amplifying exciters become rather large and therefore have large field time delays. These large field time delays make it impractical for the exciter or amplifying generators to pass higher frequencies without greatly attenuating the amplitude of the voltage wave. By connecting the exciters E1, E2 and E3 to supply the load to the synchronous motor SM and by connecting the field windings FE1, FE2 and FE3 to the generators A, B and C in a Scott connection, the exciters become voltage regulators regulating for the line to line voltage. The voltage between any two lines is compared to the voltage between the two exciters feeding that line. By building the exciters with low voltage field windings, quite high gains can be realized in each exciter. The frequency which the exciters will pass without attenuation is now increased by a factor of 1 plus the gain of the exciter. Thus an exciter with a gain of 9 and a break frequency of .1 C. P. S. will now pass a frequency of 1 C. P. S. In addition to the improved frequency performance of the exciters, the regulation of the exciters with the load is greatly improved since the regulator will recover part of the drop of the exciters.

These advantageous features pointed out become rather important as higher powers are required and as higher frequencies are required, since they permit the use of a smaller reference voltage source to obtain the equivalent performance of designing the exciters with low time delays.

Referring more specifically to the showing in Fig. 3, it will be noted that the generators A, B and C are connected as shown in Fig. 1 except that for the arrangements shown the windings of the synchronous motor are not in the load circuit of these generators, but the field windings FE1, FE2 and FE3 and the exciters E1, E2 and E3 are in the load circuits of these generators. For example, if we start viewing the circuit from the common junction 14, it will be noted that the circuit for generator A may be traced from that junction through the armature of generator A, the field winding FE1 of the exciter E1, the common junction 141 for the exciters, the exciter E2, field winding FE2, the armature of generator B back to the common junction 14. For the generator C, the circuit may be traced from the common junction 14 through the armature of generator A, the field winding FE1 of the exciter E1, common junction 141, the armature of exciter E3, the field winding FE3, the armature of generator C to the common junction 14. It will be noted that this circuitry is again a Scott circuit but with the field windings FE1, FE2 and FE3 of the exciters E1, E2 and E3 and the armatures of these exciters now in the load circuits of the generators A, B and C. With this arrangement the oscillator type of circuit may be maintained relatively small with reference to the synchronous motor since the exciters E1, E2 and E3 now comprise the generators which supply the low frequency to the synchronous motor.

For example, if the circuit for the synchronous motor is to be traced from the common junction 141, it will be noted that the exciter E1 through switch contacts 11 connects directly to the terminal 8 of the synchronous motor. Similarly, the exciter E2 is connected directly to the terminal 9 of the synchronous motor through switch contacts 12 and exciter E3 is connected directly to the terminal 7 of the synchronous motor through switch contact 10.

The two modifications, namely the modification shown in Fig. 1 and that shown in Fig. 3, now make it possible to provide low frequencies to synchronous motors ranging from relatively small synchronous motors to the very largest used in the trade.

I have tested my systems of control to verify the phase, frequency, and voltage relations of the outputs of the generators, and such tests proved that my present system performs as expected, and I believe my present system of control, for the type of output desired, represents the minimum in equipment required with respect to the numerous other prior art systems of control now in use for producing low frequency, three-phase power.

I claim as my invention:

1. In an electric system of control, in combination, a first generator having a self-energizing field winding connected across its armature terminals, a second and a third generator each having self-energizing field windings connected in series to the opposite armature terminals of the second and third generators, the first generator having a differential field winding connected to the opposite armature terminals of the second and third generators, and the second and third generators each having a control field winding, said control field windings being connected in series across the armature terminals of the first generator, whereby each of the generators will have alternating current output with the output of one generator having a definite phase lag with respect to the other generators, said generators being connected in a T network to produce a typical three-phase output at the outer terminals of the T network.

2. In an electric system of control, in combination, a first generator having a self-energizing field winding connected across its armature terminals, a second and a third generator each having self-energizing field windings con-

nected in series to the opposite armature terminals of the second and third generators, the first generator having a differential field winding connected to the opposite armature terminals of the second and third generators, the second and third generators each having a control field winding, said control field windings being connected in series across the armature terminals of the first generator, whereby each of the generators will have alternating current output with the output of one generator having a definite phase lag with respect to the other generators, said generators being connected in a T network to produce a typical three-phase output at the outer terminals of the T network, and a three-phase load connected to the outer terminals of the T connection.

3. In an electric system of control, in combination, three direct current generators, comprising a first generator and other two generators, the armature of said generators being connected in a T connection, said generators each having control field windings, the control field winding of said first generator being excited from the other generators and the control field windings of the other generators being excited from the first generator, self-energizing field windings for each of the generators, the self-energizing field winding of the first generator being connected to be energized from the voltage output of the first generator and the self-energizing field windings of the other generators being connected to be energized from the combined voltage output of the other generators, and oscillation control field windings for each generator, the one for the first generator being connected in a loop circuit upon itself and the two for the other generators being connected in series upon themselves in loop circuits.

4. In an electric system of control, in combination, three direct current generators, each generator having a self-energizing field winding, each generator having a control field winding, the control field winding of one generator being energized from the other two generators and the control field windings of the other two generators being energized from the first generator, the control field winding of said one generator being wound to be differential to the self-energizing field winding whereby the generators will have an alternating current output with the output of one generator having a definite phase lag with respect to the combined output of the other generators, said generators being connected in a T connection to provide a three-phase output voltage at the outer terminals of the T connection.

5. In an electric system of control, in combination, three direct current generators, each generator having a self-energizing field winding, each generator having a control field winding, the control field winding on one generator being energized from the other two generators and the control field windings of the other two generators being energized from the first generator, the control field winding of the said one generator being wound to be differential to the self-energizing field winding whereby the generators will have an alternating current output with the output of one generator having a definite phase lag with respect to the combined output of the other generators, said generators being connected in a T connection to provide a three-phase output voltage at the outer terminals of the T connection, and excitation means for each generator for varying the frequency of the outputs of the generators.

6. In an electric system of control, in combination, three direct current generators, each generator having a self-energizing field winding, each generator having a control field winding, the control field winding of one generator being energized from the other two generators and the control field windings of the other two generators being energized from the first generator, the control field winding of the said one generator being wound to be differential to the self-energizing field winding whereby the generators will have an alternating current output with the output of one generator having a definite phase lag with respect to the combined output of the other generators, said generators being connected in a T connection to provide a three-phase output voltage at the outer terminals of the T connection, excitation means for each generator for varying the frequency of the outputs of the generators, and a three-phase load connected to the outer terminals of the T connection.

7. In an electric system of control, in combination, a first direct current generator, a second direct current generator, and a third direct current generator, a self-exciting field winding for the first generator connected across the armature terminals of the first generator, and self-exciting field windings connected in series across the armature terminals of the second and third generators to be energized as a function of the sum of the voltage outputs of the second and third generators, control field windings for the second and third generators connected in parallel to the self-exciting winding of the first generator, and a control field winding for the first generator connected in parallel to the self-exciting windings of the second and third generators, the control field winding of the first generator being wound differentially to its self-exciting field winding, whereby the generators will each produce single phase alternating currents with the outputs of the second and third generators being in phase and the output of the first generator being in quadrature, circuit means for connecting said generators in a T connection to thus produce low frequency three-phase alternating current at the output terminals of the T connection.

8. In an electric system of control, in combination, a first direct current generator, a second direct current generator, and a third direct current generator, a self-exciting field winding for the first generator connected across the armature terminals of the first generator, and self-exciting field windings connected in series across the armature terminals of the second and third generators to be energized as a function of the sum of the voltage outputs of the second and third generators, control field windings for the second and third generators connected in parallel to the self-exciting winding of the first generator, and a control field winding for the first generator connected in parallel to the self-exciting windings of the second and third generators, the control field winding of the first generator being wound differentially to its self-exciting field winding, whereby the generators will each produce single phase alternating currents with the outputs of the second and third generators being in phase and the output of the first generator being in quadrature, circuit means for connecting said generators in a T connection to thus produce low frequency three-phase alternating current at the output terminals of the T connection, and excitation means for each generator, inductively related to the circuits of the generators, for selecting the frequency of the alternating current output voltage.

9. In an electric system of control, in combination, a first direct current generator, a second direct current generator, and a third direct current generator, a self-exciting field winding for the first generator connected across the armature terminals of the first generator, and self-exciting field windings connected in series across the armature terminals of the second and third generators to be energized as a function of the sum of the voltage outputs of the second and third generators, control field windings for the second and third generators connected in parallel to the self-exciting winding of the first generator, and a control field winding for the first generator connected in parallel to the self-exciting windings of the second and third generators, the control field winding of the first generator being wound differentially to its self-exciting field winding whereby the generators will each produce single phase alternating currents with the outputs of the second and third generators being in phase and the output of the first generator being in quadrature,

circuit means for connecting said generators in a T connection to thus produce low frequency three-phase alternating current at the output terminals of the T connection, excitation means for each generator, inductively related to the circuits of the generators, for selecting the frequency of the alternating current output voltage, and a three-phase load connected to the outer terminals of the T connection.

10. In an electric system of control, in combination, a first direct current generator, a second direct current generator, and a third direct current generator, a self-exciting winding for the first generator connected across the armature terminals of the first generator, and self-exciting field windings connected in series across the armature terminals of the second and third generators to be energized as a function of the sum of the voltage outputs of the second and third generators, control field windings for the second and third generators connected in parallel to the self-exciting winding of the first generator, and a control field winding for the first generator connected in parallel to the self-exciting windings of the second and third generators, the control field winding of the first generator being wound differentially to its self-exciting field winding, whereby the generators will each produce single phase alternating currents with the outputs of the second and third generators being in phase and the output of the first generator being in quadrature, circuit means for connecting said generators in a T connection to thus produce low frequency three-phase alternating current at the output terminals of the T connection, and excitation means for each generator, inductively related to the circuits of the generator, for selecting the frequency of the alternating current output voltage, said excitation means comprising a field winding for the first generator connected in a loop circuit and a field winding for each of the other generators connected in series with each other in a loop circuit.

11. In an electric system of control, in combination, a first direct current generator, a second direct current generator, and a third direct current generator, a self-exciting field winding for the first generator connected across the armature terminals of the first generator, and self-exciting field windings connected in series across the armature terminals of the second and third generators to be energized as a function of the sum of the voltage outputs of the second and third generators, control field windings for the second and third generators connected in parallel to the self-exciting winding of the first generator, and a control field winding for the first generator connected in parallel to the self-exciting field windings of the second and third generators, the control field windings of the first generator being wound differentially to its self-exciting windings, whereby the generators will each produce single phase alternating currents with the outputs of the second and third generators being in phase and the output of the first generator being in quadrature, circuit means for connecting said generators in a T connection to thus produce low frequency three-phase alternating current at the output terminals of the T connection, excitation means for each generator, inductively related to the circuits of the generator, for selecting the frequency of the alternating current output voltage, said excitation means comprising a field winding for the first generator connected in a loop circuit and a field winding for each of the other generators connected in series with each other in a loop circuit, and a three-phase load connected to the outer terminals of the T connection.

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