

[54] **FREQUENCY CONVERSION SYSTEM**

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321/61, 321/69 R
[51] Int. Cl. H02m 5/16, H02m 5/30
[58] Field of Search 321/3, 6, 7, 60, 61, 65-67,
321/69; 322/29, 32; 307/72, 73, 151, 297,
88.5-88.7, 8, 21.5

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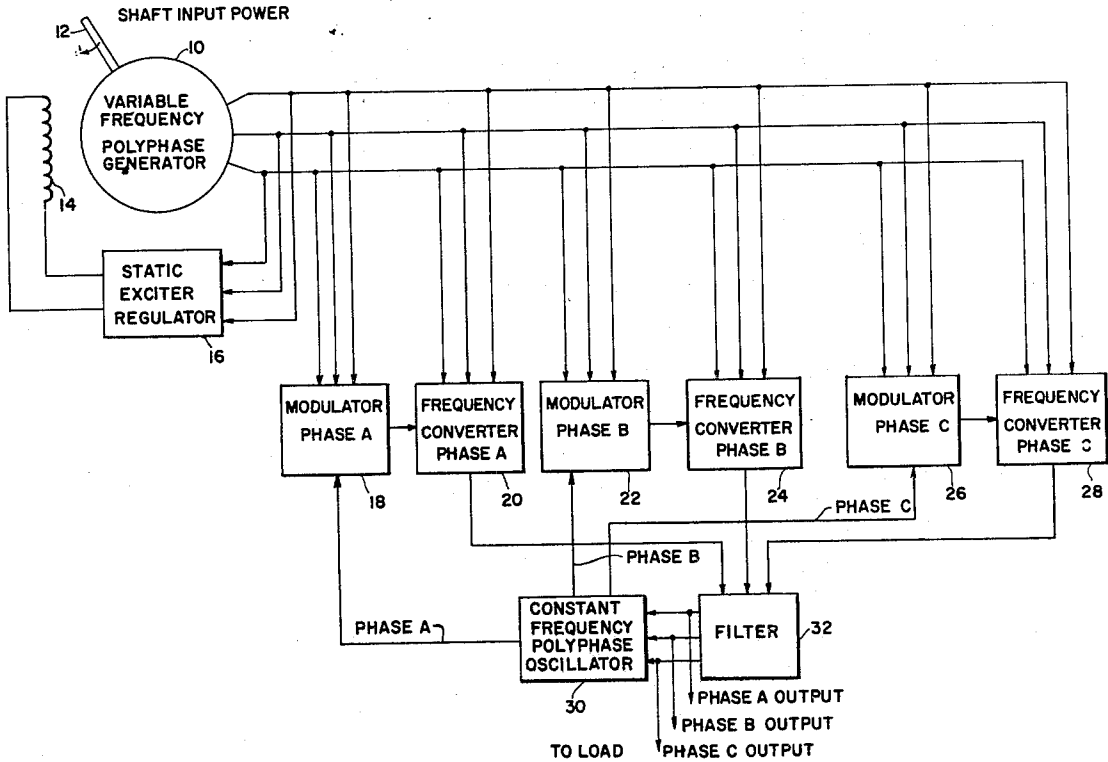
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[57] **ABSTRACT**

A power conversion system including a static cycloconverter for converting a varying input frequency signal to an output signal of constant frequency. The cycloconverter consists of a plurality of pairs of static switching devices such as silicon-controlled rectifiers which are selectively triggered into conduction to produce an output wave of the desired constant frequency. The varying input frequency signal is applied to the SCRs to furnish the supply voltage for the anode-cathode path. In addition, a reference voltage of the desired output frequency is applied along with the varying input frequency signal to a modulator for providing firing or triggering pulses for the SCRs as a function of the relative amplitudes of the reference and input signal. The modulator thus produces triggering pulses which vary in time with the signals to provide an average current which varies sinusoidally at the same frequency as the reference voltage.

36 Claims, 18 Drawing Figures



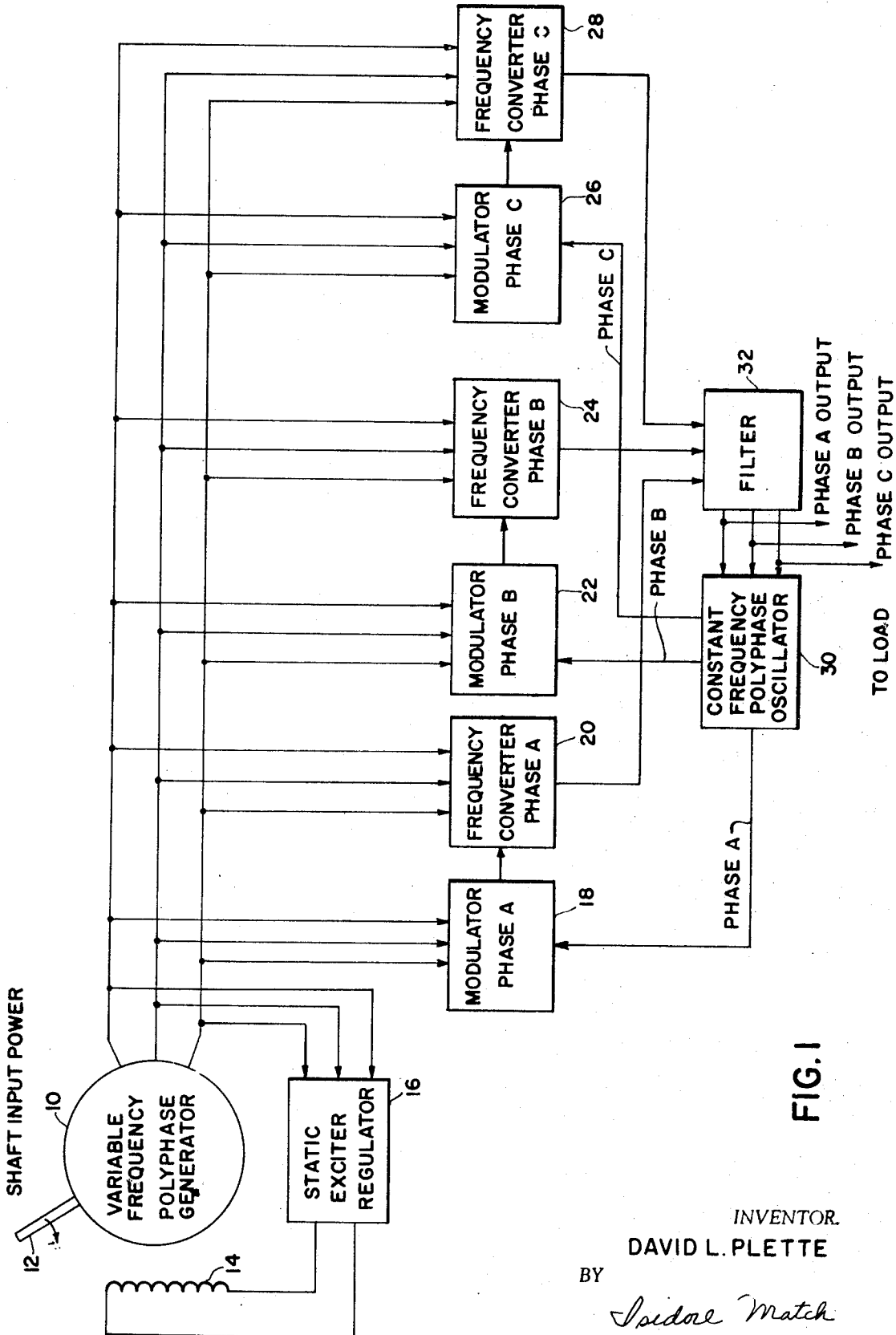
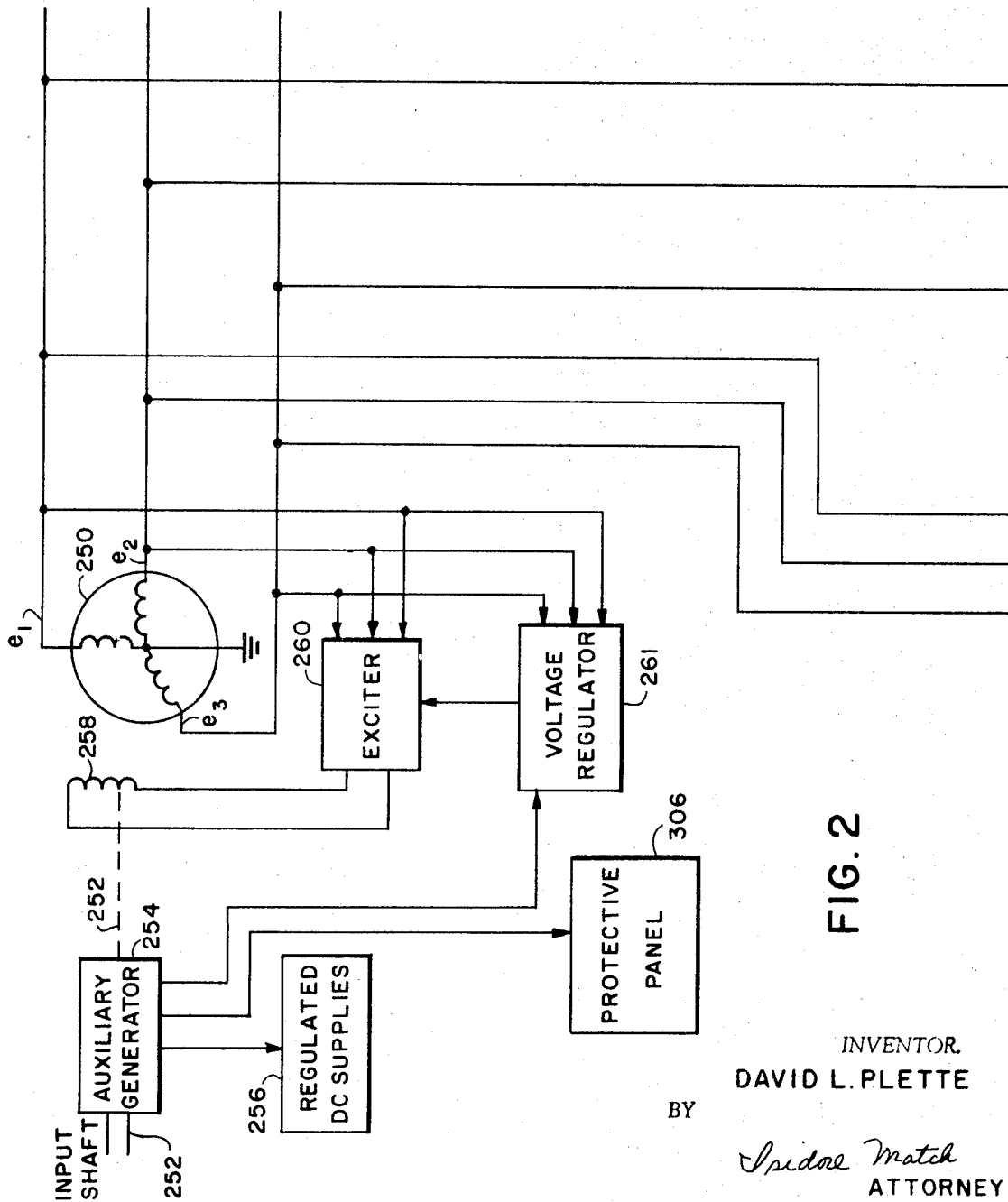


FIG. 1

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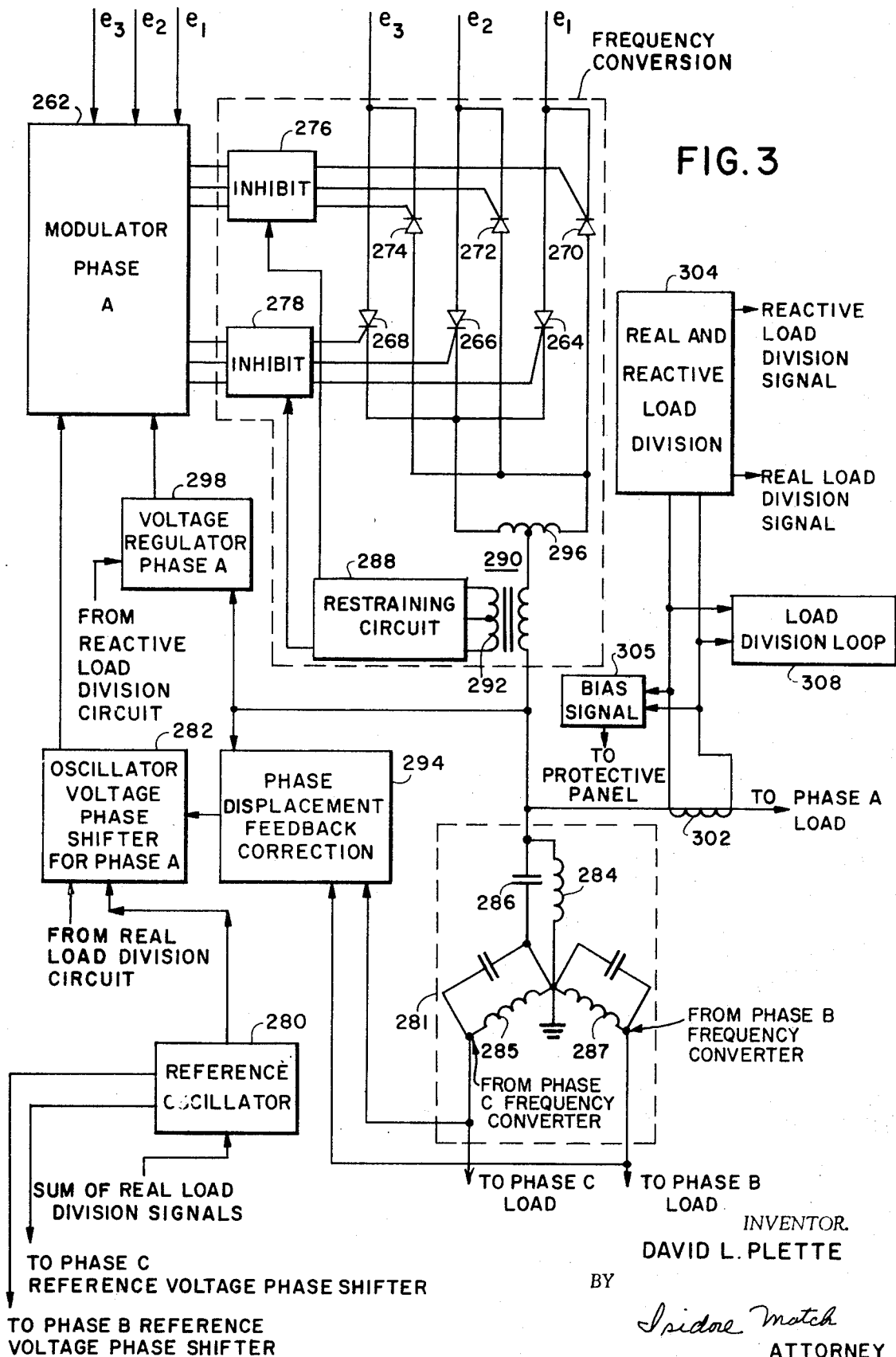


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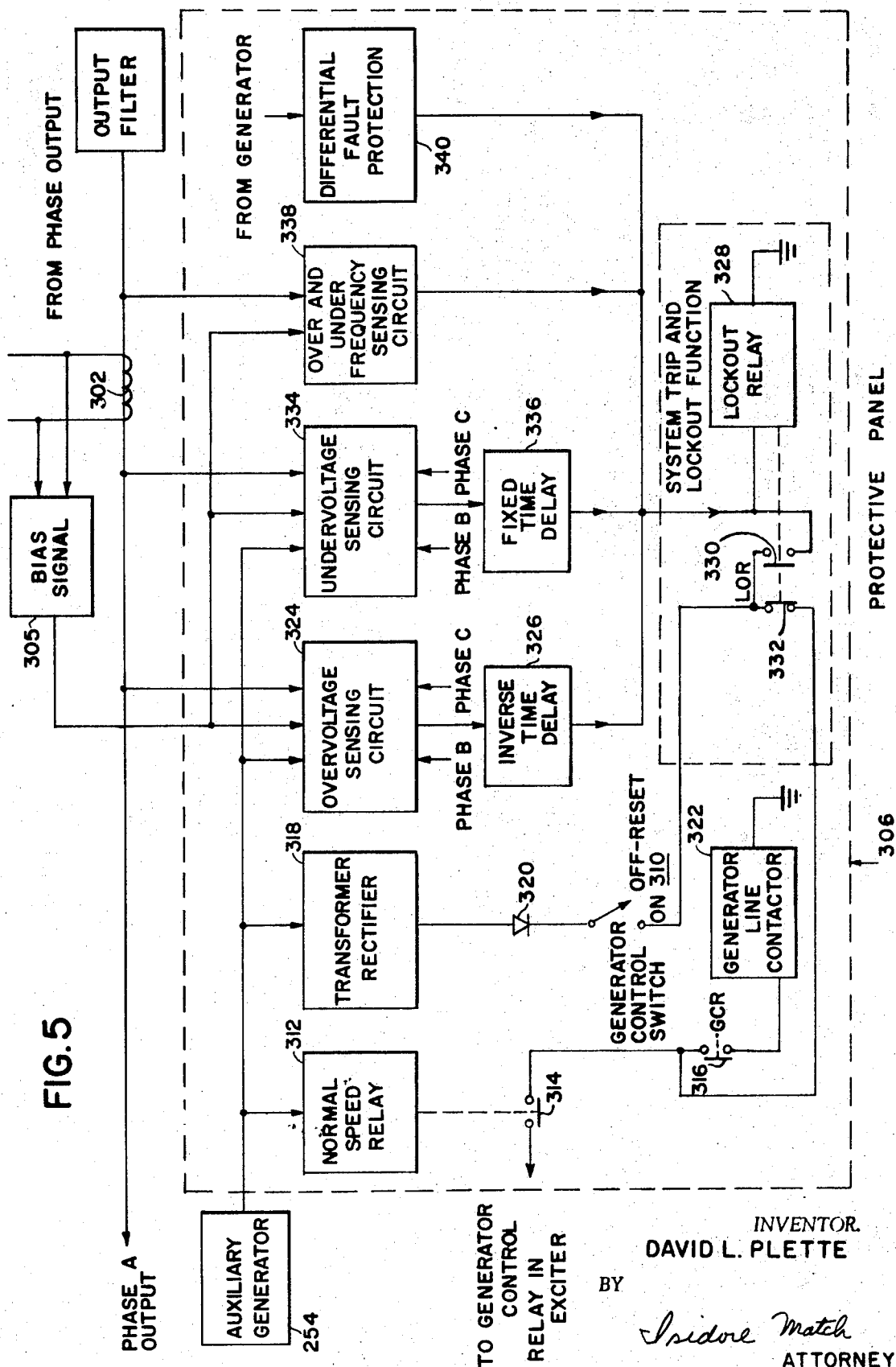
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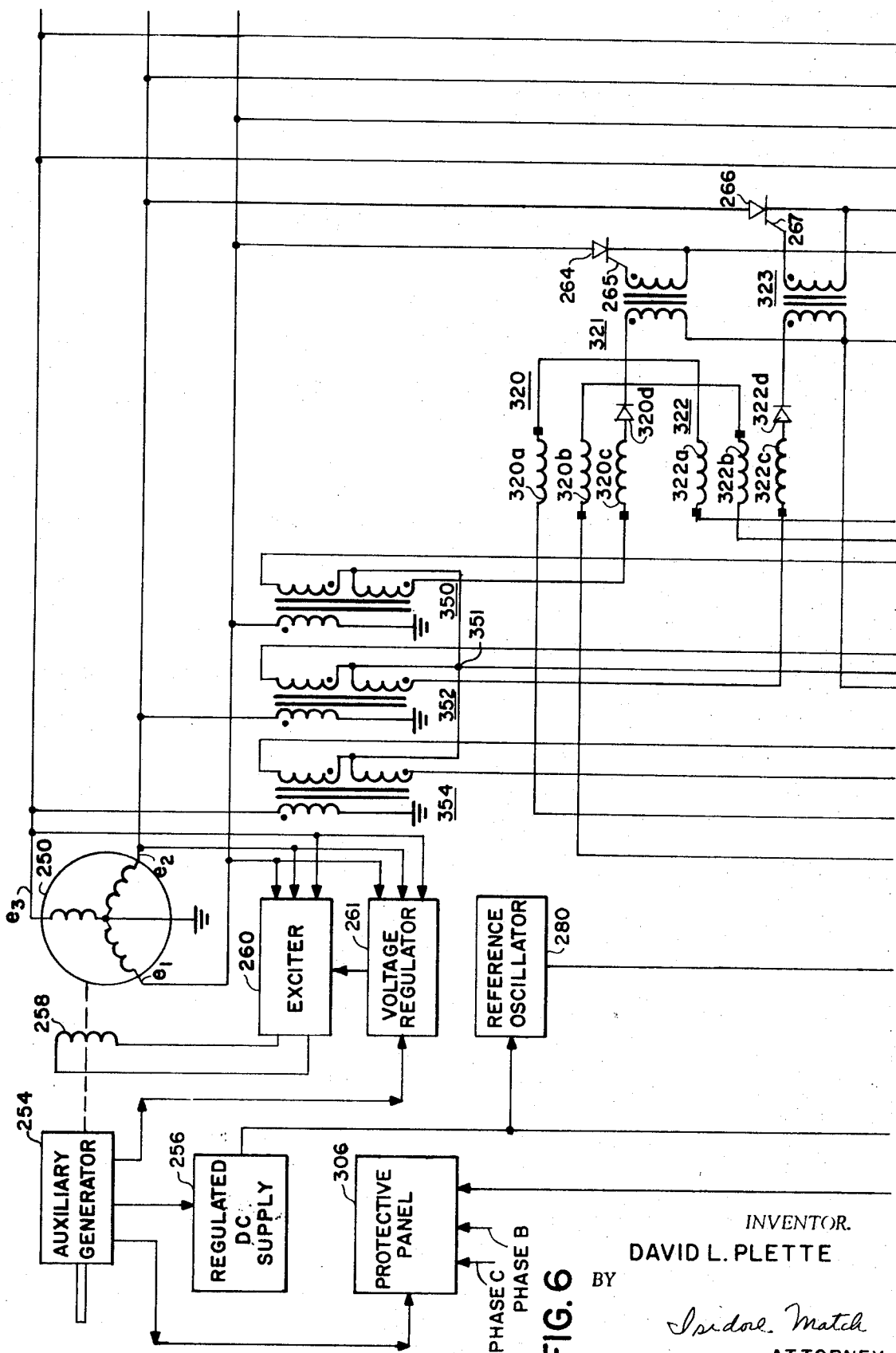


FIG. 6

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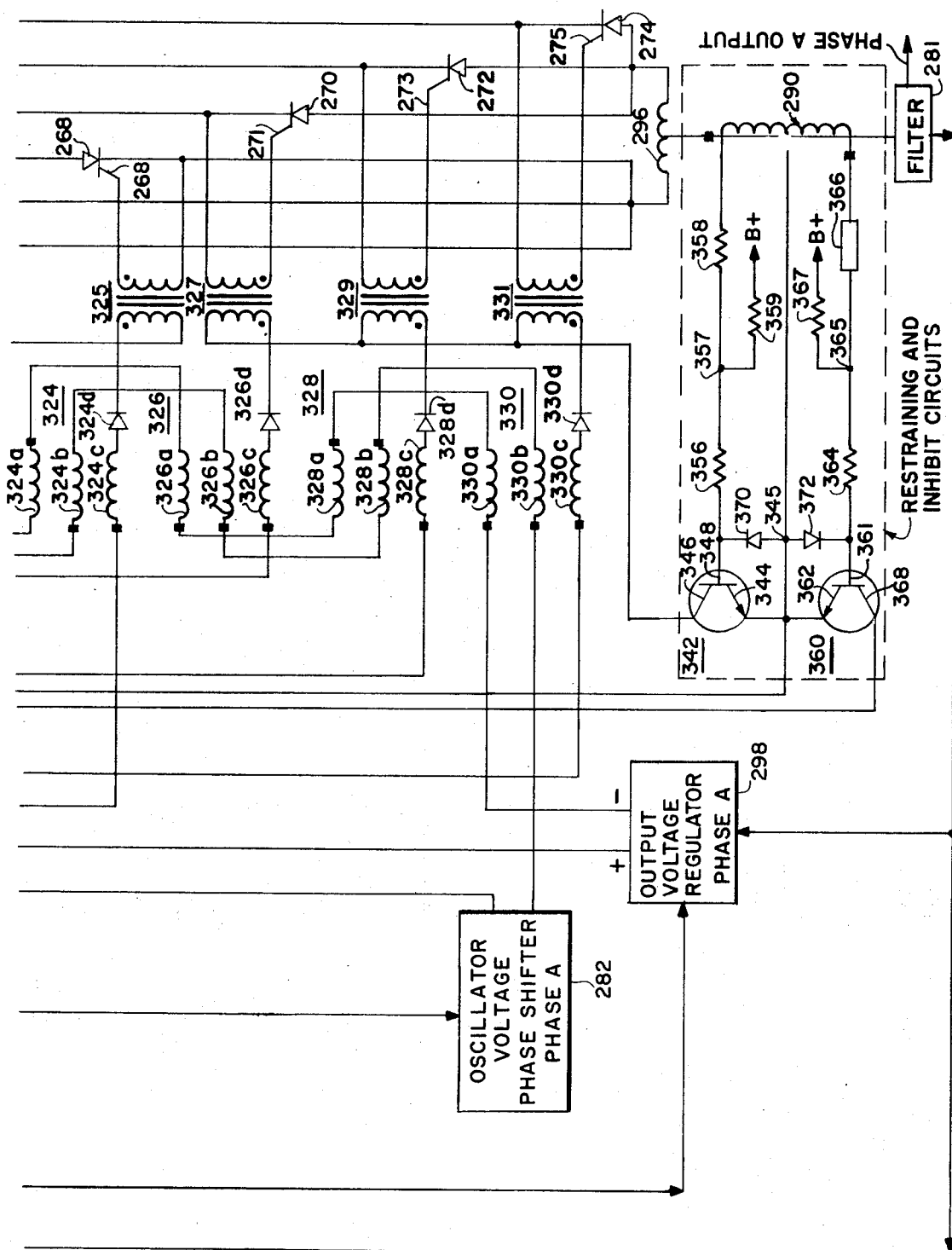


FIG. 7

FIG. 6
FIG. 7

FIG. 8

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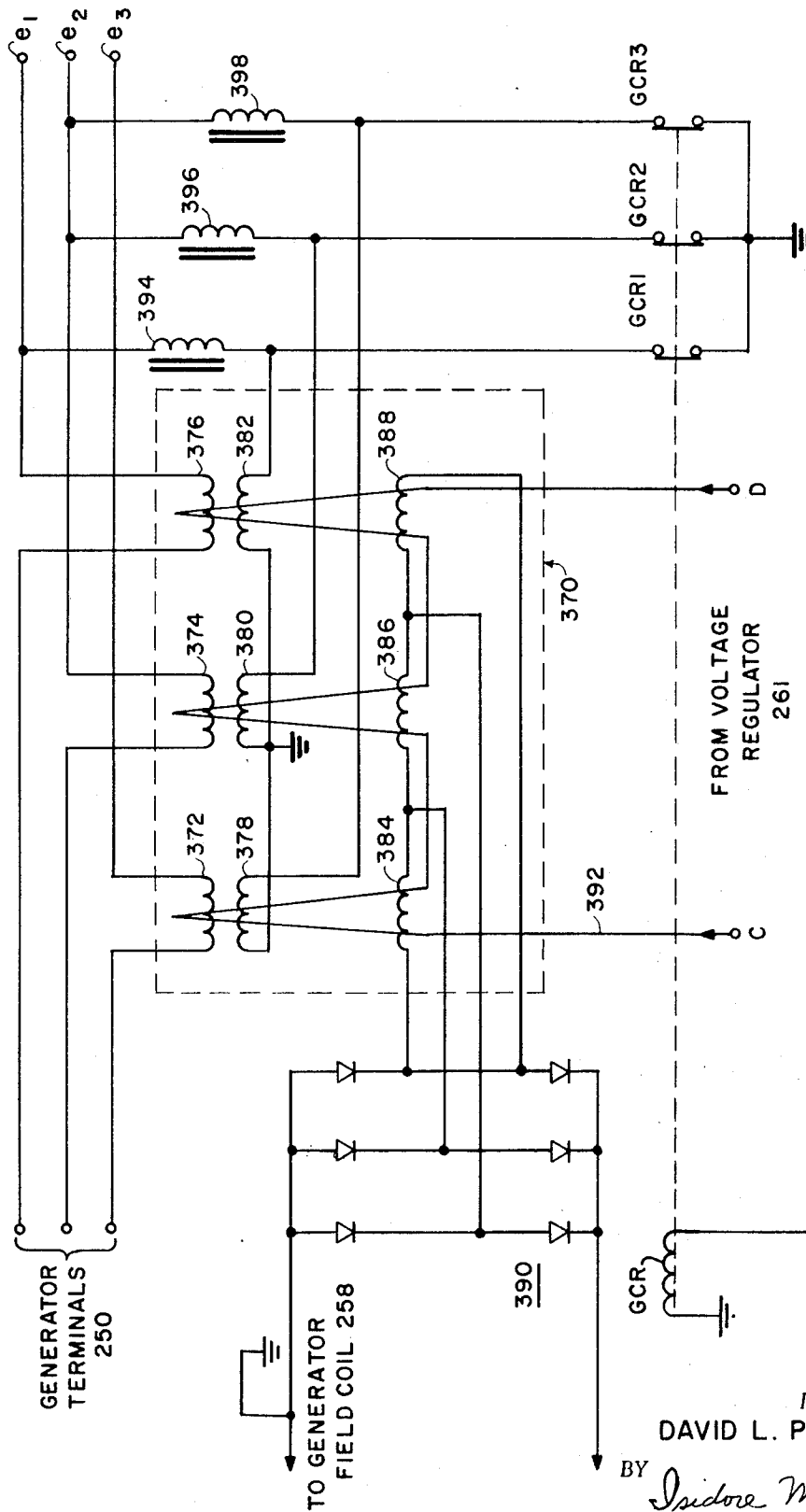


FIG. 9

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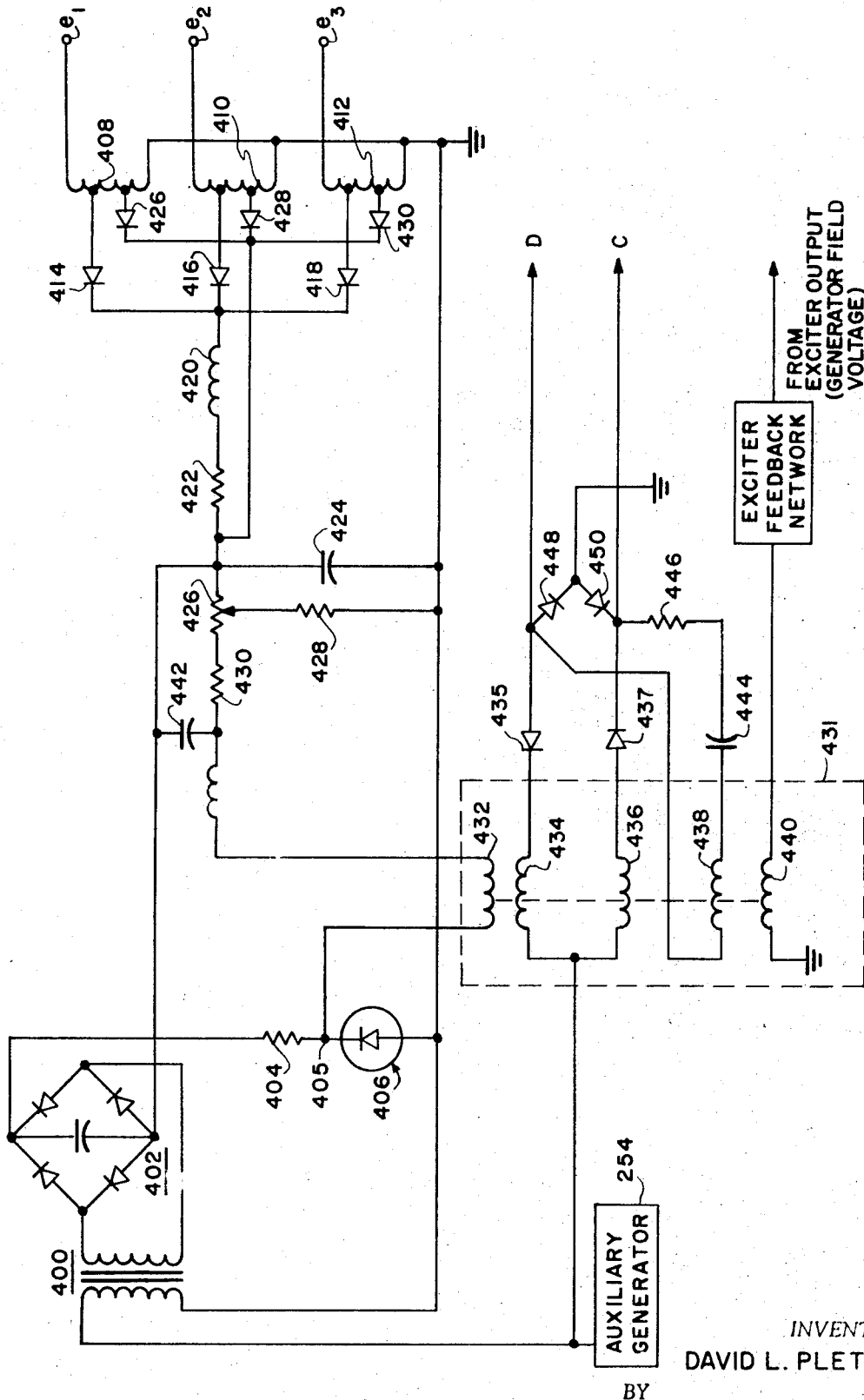


FIG. 10

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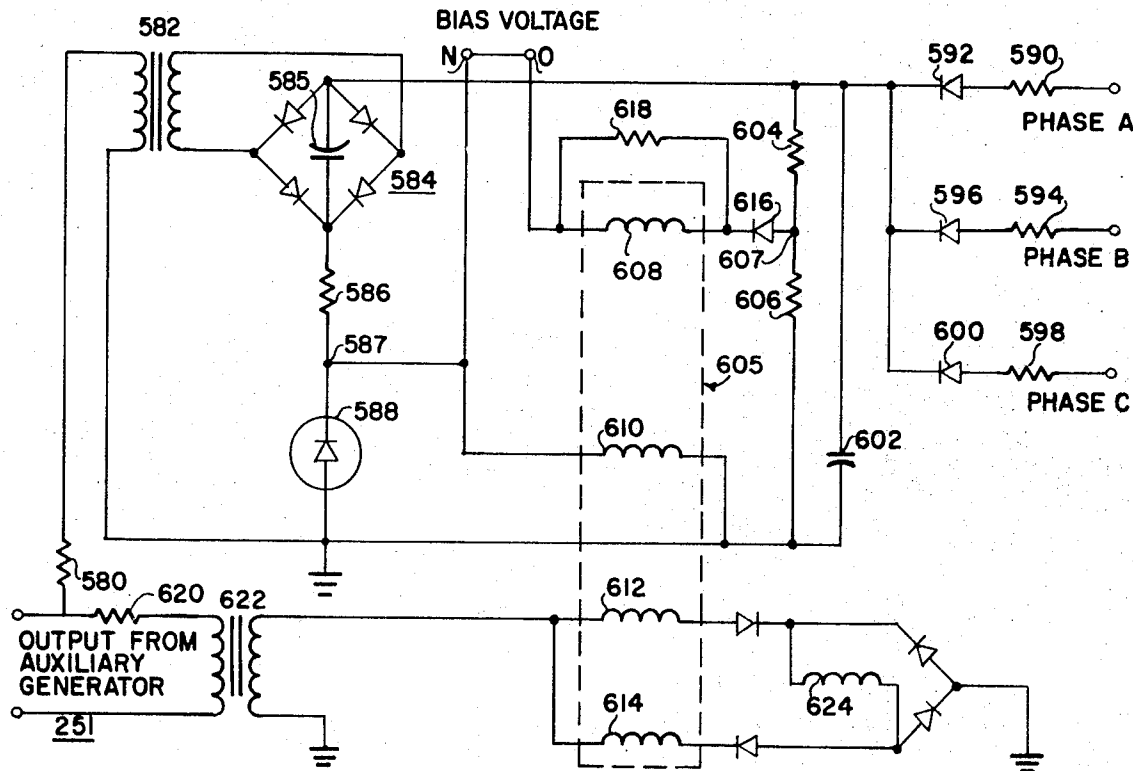


FIG. 15

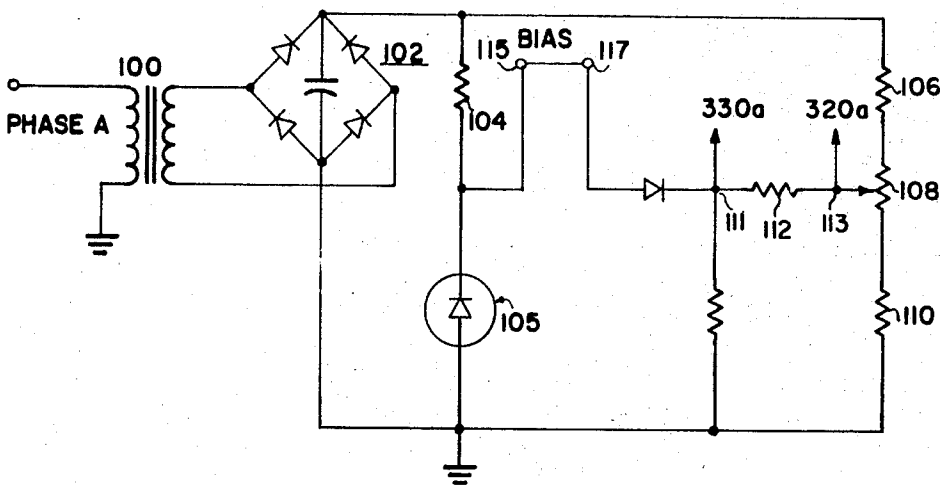
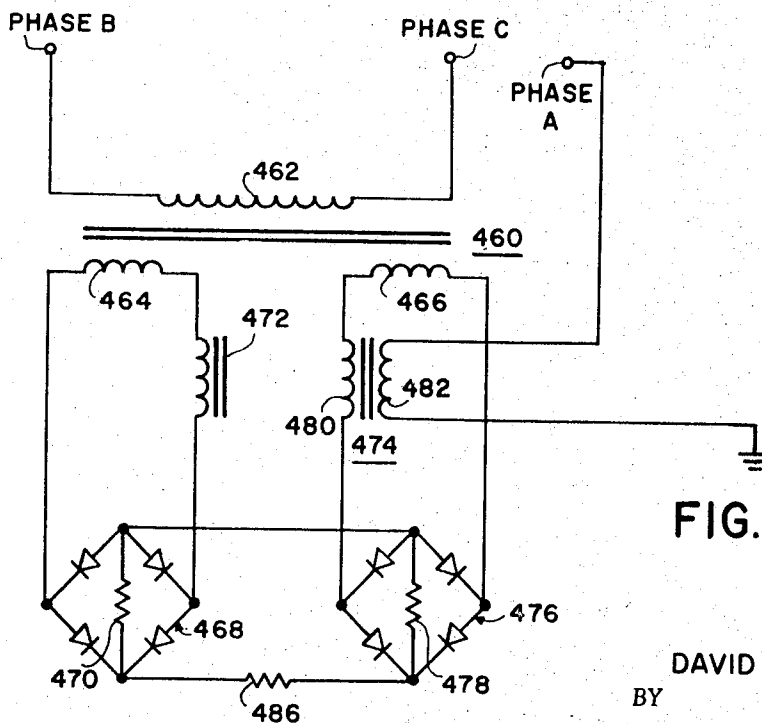
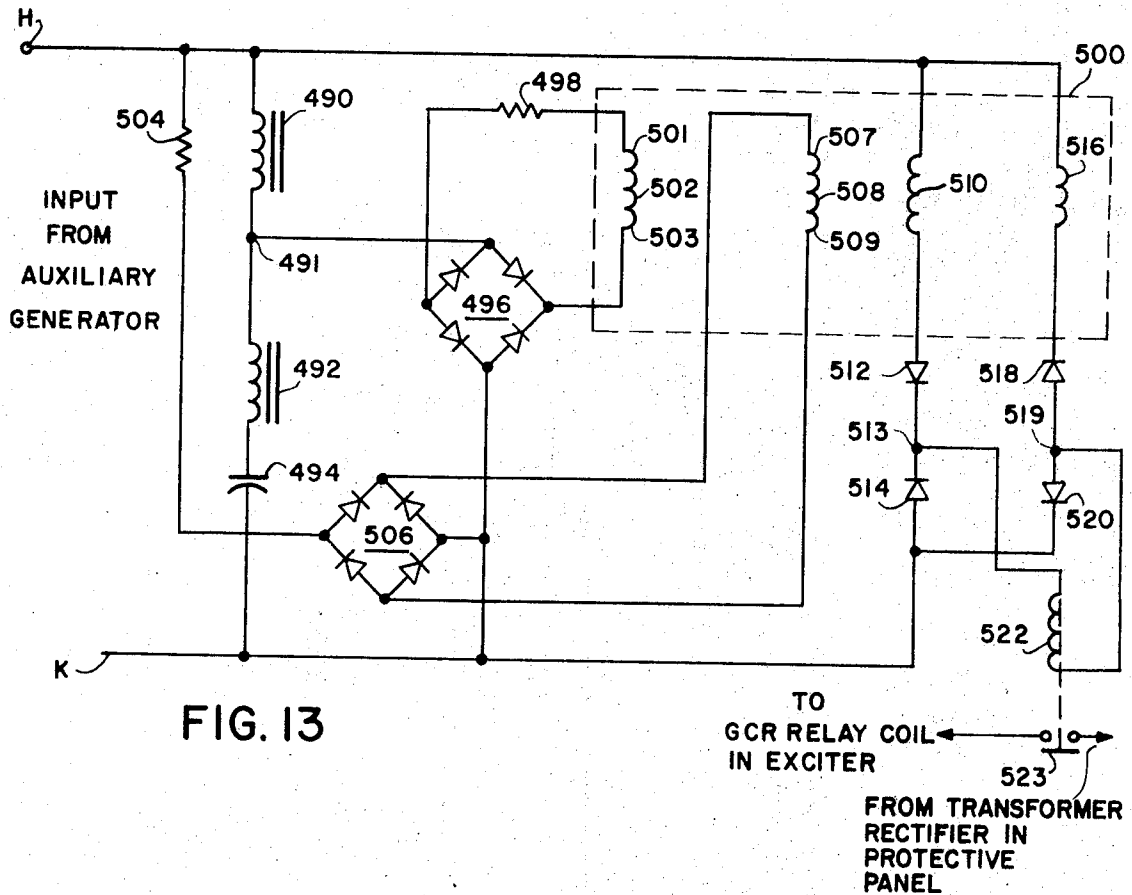
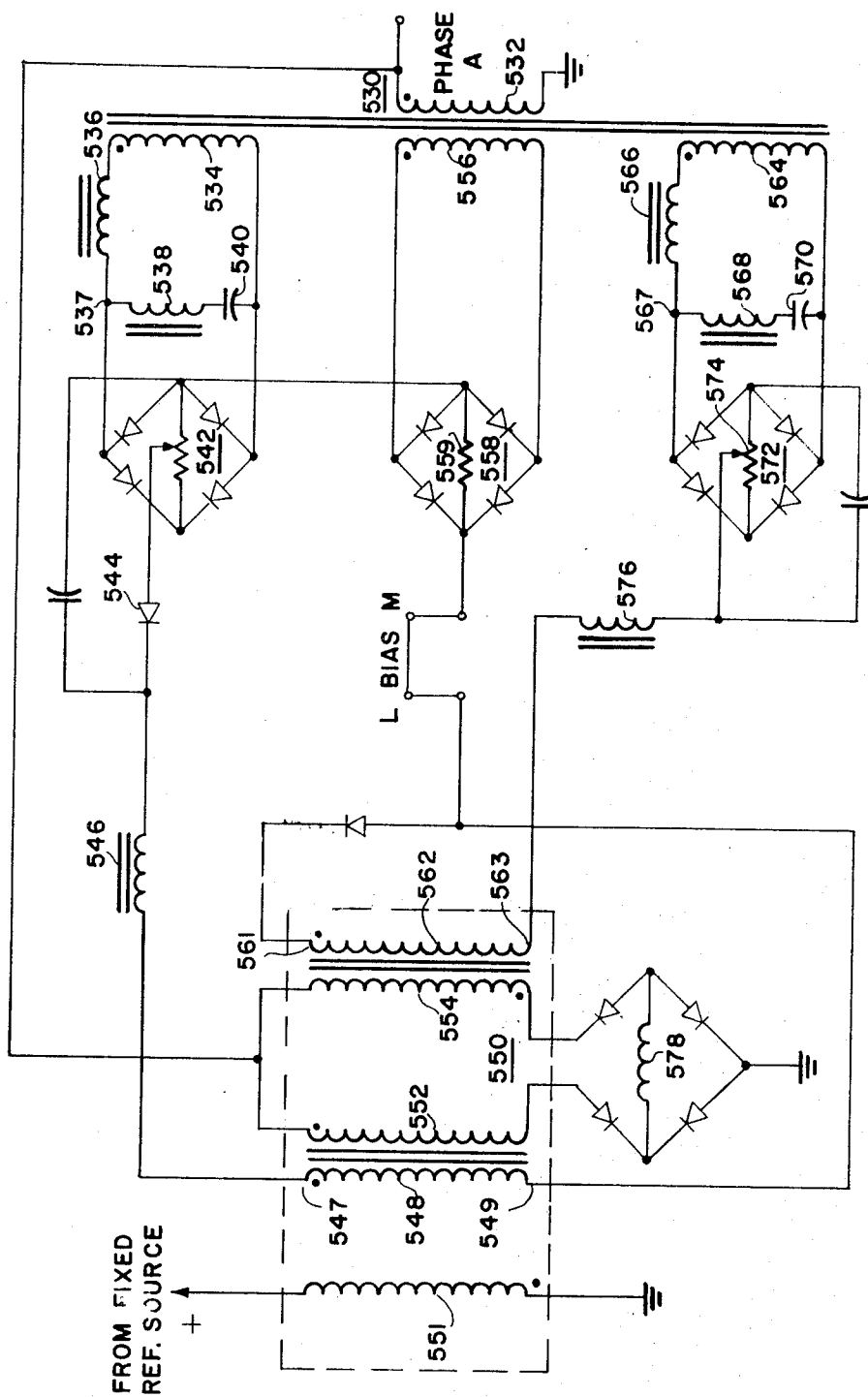


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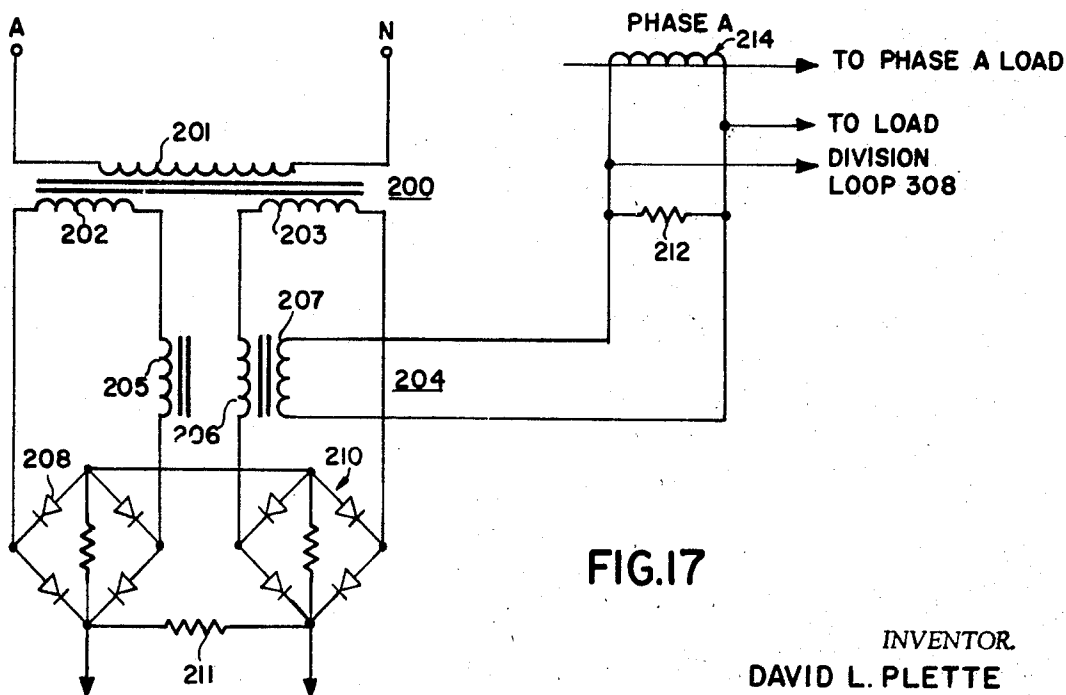
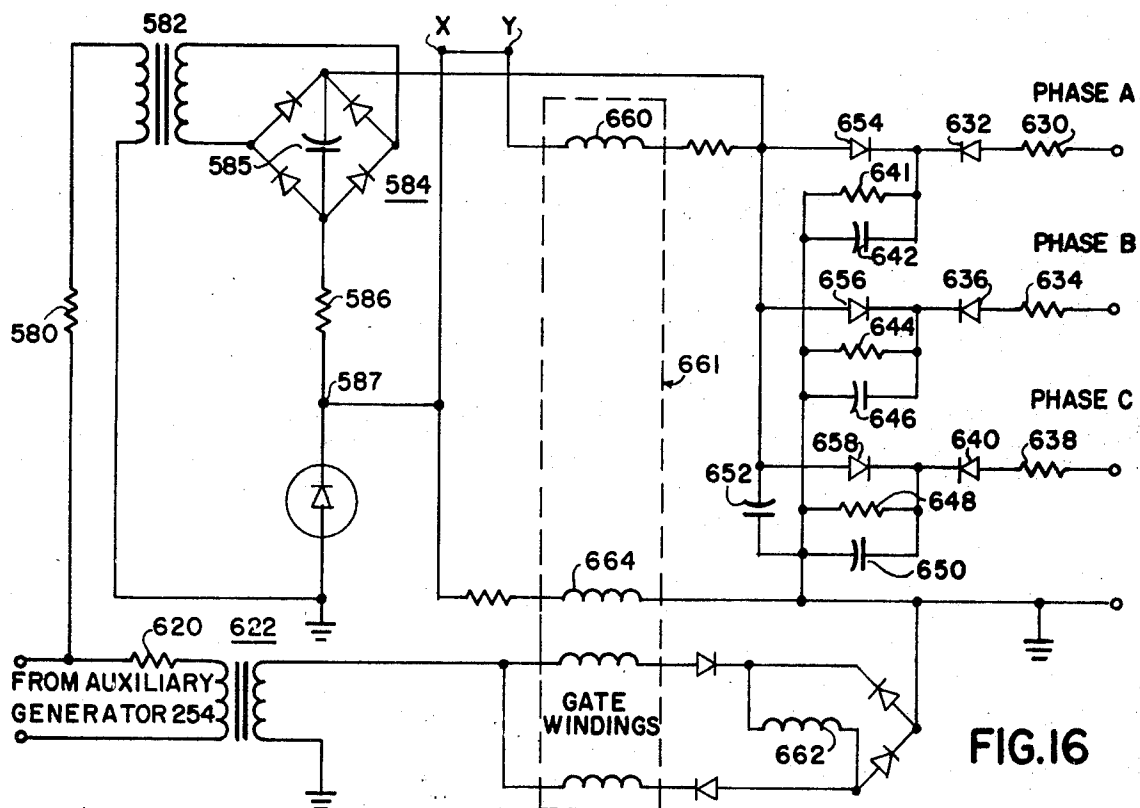
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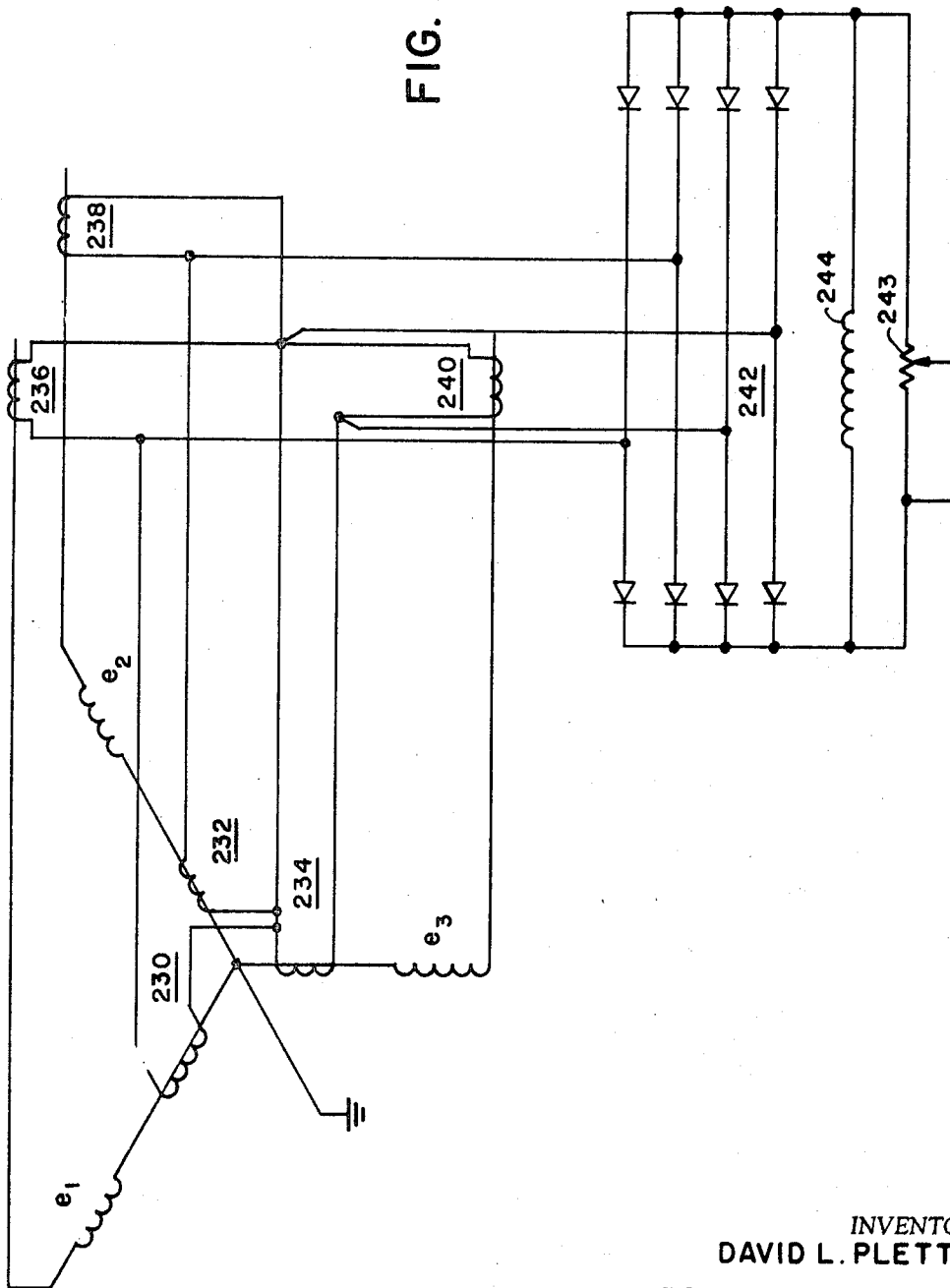
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FIG. 18



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FREQUENCY CONVERSION SYSTEM

This is a continuation of application Ser. No. 122,278 filed July 6, 1961, now abandoned.

This invention relates to frequency converter systems. More particularly, it relates to a system for providing an output having a range of determinate frequencies from a variable speed source.

In many situations such as in aircraft systems or other arrangements wherein an engine whose speed varies over a wide range is utilized to power an electrical generator it has been desirable to obtain a constant frequency output or an output having a chosen range of determinate frequencies from the variable speed source provided by such engine. Heretofore, the most widely used device for this purpose has been a hydraulic constant speed drive which is essentially a hydraulic generator-motor system which utilizes either a variable displacement generator or a motor in conjunction with a transmission to produce a continuously variable ratio over a requisite input speed range.

Such transmissions which are in general use today are quite complex and require extreme precision of moving parts together with associated piping and cooling systems. In addition, the life of such systems is relatively short and considerable maintenance thereof is required. Also, overhead costs of such systems are high and development costs for new ratings and speed ranges plus the production costs thereof are extremely high. The speed limitations of these systems serve to inhibit the development of lighter weight systems.

It is, accordingly, an important object of this invention to provide an all-electrical system for converting the variable speed shaft power provided by an engine or other energy source to a constant frequency electrical output or to an electrical output having a chosen range of determinate frequencies.

It is a further object to provide a system in accordance with the preceding object which is relatively light in weight and has relatively large power-handling capacity.

It is another object to provide a system in accordance with the preceding objects wherein considerable flexibility and selection of input speed range and output frequency is enabled and wherein the efficiency of the system is high.

Generally speaking, and in accordance with the invention, there is provided a system for providing an electrical output having a chosen range of determinable frequencies from a source having a varying indeterminate frequency comprising frequency conversion means in circuit with the source which includes a plurality of elements which can be switched from the nonconductive to the conductive state in response to switching signals respectively applied thereto. There is included in the system a reference source for providing an output having such range of determinable frequencies and means for mixing the output of both sources. Means are included responsive to the resultant of the mixed outputs for providing the aforesaid switching signals to the elements in accordance with the reference, and means are provided for combining the consequent outputs of these elements, such combining producing a resultant output having the chosen range of frequencies.

The features of this invention which are believed to be new are set forth with particularity in the appended claims. The invention itself, however, may best be understood by reference to the following description when taken in conjunction with the accompanying drawings which show embodiments of a frequency converter according to the invention.

In the drawings, FIG. 1 is a block diagram of the system of this invention;

FIGS. 2 and 3, taken together as shown in FIG. 4, is a diagram, partly in block form and partly schematic, illustrating a portion of another embodiment of the system for providing one of the phase outputs thereof;

FIG. 5 is a block diagram of a protective arrangement which may be utilized in conjunction with the system of the invention;

FIGS. 6 and 7, taken together as shown in FIG. 8, comprise a diagram, partly in block form and partly schematic, which illustrates the modulator and the restraining and inhibit circuits of FIGS. 2-4 for a single output phase;

FIG. 9 is a schematic depiction of an exciter suitable for use in the system of FIGS. 2-4;

FIG. 10 is a schematic depiction of a first type of voltage regulator suitable for use in the system of FIGS. 2-4;

FIG. 11 is a schematic depiction of a second type of voltage regulator suitable for use in the system of FIGS. 2-4;

FIG. 12 is a schematic depiction of a circuit for deriving phase displacement correction signals;

FIG. 13 is a schematic depiction of a circuit suitable for use as the normal speed relay in the protective arrangement shown in block form in FIG. 5;

FIG. 14 is a schematic depiction of a circuit suitable for use as the over and underfrequency sensing stage in the protective arrangement;

FIG. 15 is a schematic diagram of a circuit suitable to provide the overvoltage sensing and time delay functions in the protective arrangement;

FIG. 16 is a schematic diagram of a circuit suitable for use as the undervoltage sensing stage of the protective arrangement;

FIG. 17 is a schematic diagram of a circuit suitable for use to provide real and reactive load division signals in a parallel system and to provide bias signals for under and overfrequency sensing circuits in a parallel arrangement; and

FIG. 18 is a schematic depiction of a circuit suitable for use as the differential fault protection stage of the protective arrangement.

Referring now to FIG. 1 wherein there is shown an embodiment of a system in accordance with the invention, a generator 10 in response to the application thereto of the variable speed power of shaft 12 produces a three-phase output, the outputs having a frequency in accordance with the speed of shaft 12. The field winding 14 of generator 10 is excited by an exciter 16 which may suitably be of the static type, exciter 16 having feedback thereto the three-balanced phase outputs of generator 10, stage 16 containing voltage regulating means whereby the output of generator 10 is maintained at a relatively constant voltage level.

For providing three outputs from the system which are equally displaced in phase, a modulator and a frequency converter are provided for producing each system output. Thus for phase A, there is provided modulator 18 and frequency converter 20; for phase B, there is provided modulator 22 and frequency converter 24; and for phase C, there is provided modulator 26 and frequency converter 28. An oscillator 30 having a three-phase output of relatively constant frequency or a determinable range of frequencies provides a reference frequency voltage for modulators 18, 22 and 26, respectively.

In the frequency converters 20, 24 and 28, there are included power switching devices which in response to switching signals respectively applied thereto perform the frequency conversion in the system. Since the unfiltered outputs of the frequency converters contain components having undesired frequencies as well as those of the desired frequency, the output filter 32 serves to substantially remove the undesirable components.

In the modulators, one of the respective phase outputs of oscillator 30 is mixed with the three phase outputs of oscillator 30 to provide the proper switching signals for the switching devices in the frequency converters. The exciter regulator 16 functions to control the excitation in generator 10 so that the proper voltages are applied to the frequency converters.

The oscillator stage 30 contains an oscillator, the frequency of the output of which determines the frequency of the output of the system and a phase splitter or like device which determines the system phase displacement and phase sequence. The frequency of generator 10 is suitably chosen to be a function of the frequency of oscillator 30 such as about four to 20 times the oscillator frequency. This adjustment may be ac-

complished by changing the number of poles on generator 10, for example.

In FIGS. 2-4, there is shown an embodiment of one stage of the frequency conversion system in accordance with the principles of the invention wherein the generator voltages are provided by an AC generator. The switching devices used for frequency conversion are silicon-controlled rectifiers and the modulator for determining the firing progression of the silicon-controlled rectifiers comprises a plurality of magnetic amplifiers, one magnetic amplifier being associated with each controlled rectifier. In FIGS. 2-4, there are shown the elements comprising that part of the system for providing one of the output phases thereof and is conveniently referred to as the phase A output.

Referring now to FIGS. 2-4, there is shown therein an AC generator 250 which provides a three-phase output, viz, voltages e_1 , e_2 and e_3 in response to the rotatory mechanical input applied thereto by shaft 252. Generator 250 suitably may be of the inductor type, such type having no rotating winding or rotating semiconductor devices whereby a simple and reliable form of generator results. Generator 250 may conveniently comprise six pairs of poles. Thus with a mechanical input thereto of from 17,200 to 31,200 r.p.m. a sinusoidal output is provided therefrom having a frequency of from about 1,720 to 3,120 cps.

Mounted on shaft 252, as generator 250, is an auxiliary generator 254 which is utilized as a voltage source to provide the supply for the components of the electrical system such as magnetic amplifiers, transistors, etc. Such auxiliary generator is provided to insure that the system is conditioned for operation prior to the energization of generator 250, and is also utilized to provide AC voltage supplies to stages in the protective panel 306 as will be explained further hereinbelow. Auxiliary generator 254 may suitably be of the permanent magnet generator type and may also comprise six pairs of poles similar to generator 250 whereby the output of the permanent magnet generator is a voltage having an amplitude proportional to the speed of shaft 252 and an output frequency in cps. which is equal to six times such shaft speed in r.p.s. The AC output of the auxiliary generator 254 is applied to a stage 256 wherefrom there is produced a regulated positive DC voltage and a regulated negative DC voltage, stage 256 suitably comprising a full-wave rectifier, a low-pass filter and a transistor voltage regulator, all of the latter elements being well known in the art.

To energize the field coil 258 of generator 250, there is provided an exciter 260, exciter 260 being enabled only after DC voltages are produced from stage 256, generator 250 being energized at such time. Exciter 260 may suitably be of the static type and has applied thereto the three-phase outputs of generators 250. Voltage regulator 261 also has applied thereto the three phase outputs of generator 250, the output of regulator 261 controlling the output of exciter 260. Accordingly, exciter 260 in addition to energizing the field coil 258 of generator 260 thereby energizing the generator also serves to regulate the voltage of the three-phase outputs from generator.

The three-phase balanced outputs, voltages e_1 , e_2 and e_3 , respectively, each phase being displaced from the other by 120° , are applied to a modulator 262 in the arrangement for providing the constant frequency phase A output. It is, of course, understood that a modulator such as stage 262 is also included in the system to produce the constant frequency phase B and phase C outputs.

The power conversion elements comprising the frequency converter are the silicon-controlled rectifiers. In FIGS. 2-4, it is seen that six controlled rectifiers, i.e., three pairs of back-to-back rectifiers, one pair for each output from generator 250 are provided in a frequency converter, there being included in the system a frequency converter for the phase B and phase C outputs.

Thus, associated with modulator 262 are the silicon-controlled rectifiers 264, 266 and 268 having their anodes con-

nected to the phase e_1 , e_2 and e_3 outputs, respectively of generator 250, the cathodes of rectifiers 264, 266 and 268 being connected to one terminal of an inductor 296 and silicon-controlled rectifiers 270, 272 and 274 having their cathodes connected to the phase e_1 , e_2 and e_3 outputs, respectively, of generator 250, the anodes of silicon-controlled rectifiers 270, 272 and 274 being connected to the other terminal of inductor 296. In the depiction of the system in FIGS. 2-4, it is seen that one portion of modulator 262 controls the firing of silicon-controlled rectifiers 264, 266 and 268 and one portion of modulator 262 controls the firing of silicon-controlled rectifiers 270, 272 and 274, the firing being influenced, respectively by inhibit circuits 276 and 278, respectively, the function of which will be explained further hereinbelow.

Also applied to modulator 262 is the output of a reference sinusoidal oscillator 280 which suitably has a frequency that is a relatively small fraction of the value of the frequency of the respective outputs of generator 250. Thus, where the frequency of generator 250 is in the range of the aforesaid 1,720 to 3,120 cps., the output of oscillator 280 may conveniently have a frequency of about 400 cps., the latter frequency being the constant frequency of each phase output of the system. Also, oscillator 280 may be a variable frequency oscillator having a range of output frequencies.

The output of oscillator 280 is applied to a phase shifter 282, this being the stage for providing the reference voltage for the phase A output. The output of phase shifter 282 is also applied to respective modulators (not shown in FIGS. 2-4) for providing the phase B and phase C reference voltages, each of the outputs of phase shifter 282, viz, the phase A, B and C reference voltages normally being displaced in phase with respect to each other by 120° .

A modulator for each phase such as modulator 262 may suitably comprise in a situation where three back-to-back pairs of silicon-controlled rectifiers are utilized, six magnetic amplifiers, each magnetic amplifier controlling the firing of a discrete silicon controlled rectifier. Thus, in a modulator such as modulator 262 for the phase A output, the output from phase shifter 282 and the output from one phase output of generator 250, for example, voltage e_1 are applied to a control winding and a gate winding of an associated magnetic amplifier, silicon-controlled rectifier 264 being switched into conductivity by the output of the magnetic amplifier. Thus, for example, a magnetic amplifier is fired during a positive half cycle of the e_1 voltage to switch a silicon-controlled rectifier such as 264 into conductivity. A silicon-controlled rectifier such as rectifier 270 is switched into conductivity by a magnetic amplifier which if fired during a negative half cycle of voltage e_1 . The switching into conductivity of silicon-controlled rectifiers such as rectifiers 264, 266 and 268 occur during the coincidence of positive half cycles of generator voltage and positive half cycles of current output from the system and the switching into conductivity of silicon-controlled rectifiers such as rectifiers 270, 272, and 274 occur during the coincidence of negative half cycles of generator voltage and negative half cycles of current output from the system.

By utilizing three pairs of back-to-back rectifiers in the frequency conversion stage, there results an interleaving of controlled rectifier conduction period outputs which when integrated provide an output wave which is substantially a sine wave having the frequency of the output of reference oscillator 280.

With this arrangement, the amplitude of the final output wave can be controlled by shifting the firing angles of the magnetic amplifiers in the modulators. This is accomplished for each phase, say for example, phase A by comparing the voltage of the phase A output with a reference voltage in a voltage regulator 298 to provide a feedback voltage to modulator 262. Thus, if it is assumed that the phase A output has an amplitude which is below the desired amplitude, then the output from voltage regulator phase A is such as to advance the firing of the magnetic amplifiers and if the output exceeds the desired amplitude, then the output of voltage regulator 298 is such as

to retard the firing angle of the magnetic amplifiers for the phase A output. This arrangement may be utilized in all three-phase outputs of the system. The output of voltage regulator 298 is suitably applied to another control winding of a magnetic amplifier.

Stage 298 may suitably comprise a voltage regulator such as is well known in the art utilizing a Zener diode in conjunction with a transistor amplifier.

The output filtering for providing the output waveform, i.e., each of the output phases A, B and C, comprises for each phase such as for phase A, for example, the series connected inductor 296 and a parallel circuit comprising an inductor 284 and a capacitor 286. The harmonics in the outputs from the silicon-controlled rectifiers are dropped across inductor 296 since the capacitor impedance is much lower than that of inductor 296 at higher frequencies. Inductor 296 is center-tapped to produce improved commutating action when the current waveform goes through the zero crossover point. The value of the inductance of inductors 284, 285 and 287 respectively is selected to minimize the load current drawn from the system under the worst load and power factor condition.

To permit the system to handle various power factor loads, the restraining circuit 288 and inhibit circuits 276 and 278 are included. For example, let it be assumed that a 0.75 lagging power factor load is applied to the system including filter loading. In such situation, positive current would still be flowing at the completion of a positive half cycle of system output voltage. To prevent switching over from conduction in silicon-controlled rectifiers 264, 266 and 268 to conduction in silicon-controlled rectifiers 270, 272 and 274, restraining circuit 288 in conjunction with the inhibit circuits 276 and 278 prevents this commutation from taking place until the current passes through the zero crossover point. During the interval between the time that the system voltage goes through the zero crossover point and the current goes through the zero crossover point, the net power flow is back into generator 250 by inversion. Since the output current is positive during this inversion the firing of silicon-controlled rectifiers 270, 272 and 274 is delayed automatically by the inhibit circuit until the instant that the output current goes through zero, at which time the restraining circuit permits commutation to take place to silicon controlled rectifiers 270, 272 and 274, thereby permitting the negative half cycle of current to flow. Restraining circuit 288 may suitably comprise separate transistor amplifiers for the outputs appearing at the upper and lower terminals of the secondary winding 292 of the current transformer 290, such outputs being provided as feedback voltages which prevent the firing of the particular controlled rectifier by modulator 262 until the zero current crossover point is attained. Actually, inhibit circuits 276 and 278 are part of the restraining circuit which prevent the firing of controlled rectifiers 264, 266 and 268 as long as current is being carried by controlled rectifiers 270, 272 or 274, and vice versa. They are depicted in FIGS. 2-4 in separate stages merely to indicate their functional purport.

Included in circuit between the output, (phase A, for example) and the oscillator voltage phase shifter 282 is a phase displacement feedback correction stage 294, such type phase displacement stage functioning to keep the phase displacement of the outputs at 120 electrical degrees. Such stage is suitably included since unbalanced loads on the output of the system may produce varying amounts of phase shift through the frequency conversion stages and the filter circuits.

Phase displacement feedback correction stage 294 suitably comprises a circuit wherein the phase displacements of the output voltages are sensed and corrected by modifying the amount of phase shift obtained in each phase shifter such as the phase A phase shifter 282. By utilizing a stage such as the phase displacement feedback correction stage 294 in conjunction with the voltage regulator stage 298, the system is rendered relatively insensitive to unbalanced loads.

An output such as the phase A output is depicted in FIGS. 2-4 as being coupled into a real and reactive load division

stage 304, such coupling being effected by a differential current transformer loop 308. Stage 304 is utilized when it is desired to provide parallel operation of the system of this invention in conjunction with other generators or other similar systems.

In such parallel operation, there is produced from stage 304 in response to the application of a differential current thereto via current transformer loop 308, an error voltage signal which is approximately proportional to the difference between the reactive KVA carried by a single system and the average reactive KVA of all of the systems, such voltage signal suitably being obtained by phase discriminating means included in stage 304. The polarity and magnitude of this error signal is a function of the amount of reactive load shared by the system. Such error signal is applied as an input to each system phase output voltage regulator such as voltage regulator 298 as a feedback voltage. With this arrangement, equalization of the reactive KVA may be obtained in a parallel system.

Also included in stage 304 is real load division circuit to which the same signal from transformer loop 308 is applied. In response to this signal, there is produced from the real load division circuit an error voltage signal which is approximately proportional to the difference between the real load carried by a system and the average real load carried by all of the combined systems in parallel operation, such signal being suitably produced from a real load phase discriminator. The polarity and magnitude of the real load error signal is a function of the amount of real load shared by a particular system. Such real load error signal is applied as an input to phase shifter 282 to bring about a suitable change in the reference voltage phase to effect real load sharing on phase A. In addition, the arithmetic sum of such real load error signals for phases A, B, and C is applied as an input to reference oscillator 280 to bias the reference oscillator frequency. The signal which is the resultant of the arithmetic summing of the real load error signals serves to equalize the total real load between systems.

Associated with the system of this invention is a protective panel 306 for providing various protective features to the system. Each of the protective features contained in this protective panel functions to cause a halt to system operation in the event that a fault is detected. A bias signal during parallel operation is provided to protective panel 306 from stage 305. This latter signal provides a degree of selection to determine which system is faulty.

Reference is now made to FIG. 5 wherein there is shown a block diagram of the protective panel 306 of FIGS. 2-4. A first feature in the protective panel is the provision of an automatic startup and shutdown arrangement. In the operation of this function, when the generator control switch 310 is placed in the "ON" position, the system remains deenergized until minimum speed is reached. At this time, the normal speed relay stage 312, which may suitably be a circuit containing a relay which is energized at a chosen threshold frequency, senses the frequency of the output of the auxiliary generator 254. Upon the energization of the normal speed relay, normally open contacts 314 associated therewith assume the closed position and a generator control relay contained in exciter 260 (FIGS. 2-4) is energized through these closed contacts. The system then builds up to normal voltage, the contacts 316 associated with the generator control relay assuming the closed position. Generator line contactor 322 is then energized to connect the output of the generating system to the loads. Power to energize the generator control relay and generator line contactor 322 is provided from auxiliary generator 254 through transformer rectifier 318, diode 320, the ON position of generator control switch 310 and the normally closed contacts 332 associated with the lockout relay 328.

An overvoltage sensing circuit such as stage 324 in FIG. 5 is provided to sense each individual phase of the output. Stage 324 may suitably comprise a relay that is energized in a circuit which provides a unidirectional voltage essentially proportional to the higher phase voltage of the three line voltages and such voltage is compared with a reference voltage. It is seen

that the inputs to overvoltage sensing circuit 324 are the bias signal derived from stage 305, the three phase outputs and the power derived from auxiliary generator 254. The bias signal from stage 305 provides selection of the faulty system by tripping only that system causing the overvoltage on the bus. When overvoltage sensing circuit 324 is energized and with the provision of a suitable time delay in stage 326, a circuit is completed from the output thereof through the lockout relay 328 to ground. This in turn causes normally closed contacts 332 associated with lockout relay 328 to assume the open position and normally open contacts 330 associated with the lockout relay to assume the closed position whereby the circuit is opened between the output of transformer rectifier stage 318 and the generator control relay (in the exciter) as well as generator line contactor 322. Consequently, the generator control relay and the generator line contactor are deenergized and the system is disabled.

Also included in the protection panel is undervoltage sensing stage 334, such type stage also being provided for each individual phase output. Stage 334 may suitably comprise a circuit which produces a unidirectional voltage which is compared to a reference voltage to determine the existence of an undervoltage. Fixed time delay stage 336 may suitably comprise a timer or other suitable device. The undervoltage sensing and time delay circuit suitably contains a relay which, when energized, causes the energization of the lockout relay similar to the operation of overvoltage sensing circuit 334 and the system is also disabled thereby. The inputs to undervoltage sensing stage are also the three-phase outputs, the bias signal derived from stage 305 and the output of auxiliary generator 254. The bias signal from stage 305 provides a selection of the faulty system.

Stage 338, legended as an over and underfrequency sensing circuit may suitably comprise a circuit containing a relay for sensing overfrequency and a circuit containing a relay for sensing underfrequency, both of the circuits being similar to the normal speed relay circuit of stage 312, i.e., a frequency sensitive relay circuit wherein the relay is energized in response to a threshold frequency. As in the situation of the overvoltage sensing and the undervoltage sensing circuits, stages 324 and 334, the energization of the relay contained therein causes energization of lockout relay 328 and the consequent halting of operation of the system. There need only be one circuit such as stage 338 for the system since it is only necessary to test one phase output for proper frequency. The bias signal from stage 305 is also applied to stage 338 during parallel operation to provide a selection of the faulty system.

The differential faulty protection stage 340 is a circuit which senses a fault in the generator or associated feeders. The energization of a relay in the circuit of stage 340 also causes the disabling of the system via the lockout relay.

In considering the operation of the system depicted in FIGS. 2-4, it is seen that the silicon-controlled rectifiers serving as power switching devices perform the frequency conversion which results in a constant output frequency in each output phase of the system regardless of the input speed of the shaft.

The modulator for each phase provides the proper firing or control signals for the silicon-controlled rectifier devices associated therewith. The exciter for the generator in conjunction with its voltage regulator, functions to control the excitation on the generator in such a manner that the proper desired voltage is made available to the input of the frequency converter as required. The reference frequency oscillator in conjunction with phase shifter, for each phase determines the frequency of the output of the phase displacement and phase sequence of the output. A voltage regulator which is present for each phase functions to maintain essentially constant output voltage. The load division circuit sense the sharing of the real and reactive components of load between parallel systems and effect action to correct for an unequal division of loads.

In FIGS. 6-8, there is shown a depiction, partly schematic and partly in block form, of the arrangement of circuit components in the modulator, inhibit and restraining circuits, and other related system components for producing an output, such as phase A, for example, of this system.

In these FIGS., there are shown magnetic amplifiers 320, 322, 324, 326, 328 and 330. Amplifiers 320 and 326 effect the triggering of back to back pair of silicon controlled rectifiers 264 and 270, these SCR's being associated with the phase e_1 output of generator 250. The outputs of magnetic amplifiers 320 and 326 are connected to the gate electrodes 265 and 271 through transformers 321 and 327 respectively. Amplifiers 322 and 328 effect the triggering of the back to back pair of silicon-controlled rectifiers 266 and 272, these SCR's being associated with the phase e_2 output of generator 250, the outputs of magnetic amplifiers 322 and 328 being applied to the gate electrodes 267 and 273 through transformers 323 and 329 respectively. Amplifiers 324 and 330 effect the triggering of the back to back pair of silicon-controlled rectifiers 268 and 274, these SCR's being associated with the phase e_3 output of generator 250. The outputs of magnetic amplifiers 324 and 330 are applied to the gate electrodes 269 and 275 through transformers 325 and 331 respectively.

Each of the magnetic amplifiers comprise a gate winding and a pair of control windings. Thus, for example, amplifier 320 comprises a control winding 320a, a control winding 320b and a gate winding 320c, and amplifier 326 comprises a control winding 326a, a control winding 326b and a gate winding 326c. The polarity dots shown on the windings of the respective magnetic amplifiers indicate the direction of current flow therethrough to produce positive ampere turns therein.

The anode to cathode path of a diode is connected between the gate winding of the magnetic amplifier and the primary winding of its associated transformer. Thus, in circuit with magnetic amplifier 320, there is included diode 320d and in circuit with magnetic amplifier 326 there is included diode 326d. These diodes are inserted to insure that only positive current is supplied to the gating electrode of the associated silicon-controlled rectifier.

There are three inputs to each magnetic amplifier, viz, a half cycle of phase output of generator 250 which is applied to a gate winding, the reference oscillator voltage which is provided from the oscillator voltage phase shifter stage 282 and which is applied to a control winding and the output of the output voltage regulator which is also applied to a control winding. Thus, for example the output from the positive terminal of output voltage regulator stage 298 is applied to control winding 320a of amplifier 320. The control winding 320a is connected in series arrangement with control windings 322a, 324a, 326a, 328a and 330a, the polarity dot terminal of control winding 330 being connected to the negative terminal of output voltage regulator 298.

Control windings 320b, 322b, 324b, 326b, 328b, and 330b are also connected in series arrangement, the positive half cycles of voltage from oscillator voltage phase shifter 282 being applied to control windings 320b, 322b and 324b in a polarity to advance the firing and to control windings 326b, 328b and 330b in a polarity to retard the firing. Similarly, the negative half cycles of oscillator voltage are applied to control windings 326b, 328b and 330b in a polarity to advance the firing and to control windings 320b, 322b and 324b in the polarity to retard the firing.

The positive and negative half cycles of the phase e_1 output are applied to gate windings 320c and 326c respectively through transformer 350, the positive and negative half cycles of the phase e_2 output are applied to gate windings 322c and 328c respectively through transformer 352 and the positive and negative half cycles of the phase e_3 output are applied to gate windings 324c and 330c respectively through transformer

354. It is to be noted from the polarity of the windings of transformers 350, 352 and 354 respectively, as shown by the designating polarity dots, that the e_1 , e_2 and e_3 phase outputs of generator 250, applied to gate windings 326c, 328c and 330c respectively, are inverted whereby the negative half cycles of these outputs appear as positive half cycles at these gate windings. Similarly, the negative half cycles of the output of phase shifter 282 also appear as positive half cycles at control windings 326b and 328b and 330b respectively.

In considering the operation of the system of FIGS. 6—8 as described herein so far, it is seen that to provide gating current to the gating electrode of silicon-controlled rectifier, there is applied to the control winding and gate winding respectively of a magnetic amplifier, a half cycle of oscillator voltage and a half cycle of a generator phase output, the resultant firing of a magnetic amplifier effecting a triggering into conductivity of the associated silicon-controlled rectifier. It is recalled that the voltage of an output of the system, for example, the phase A output is compared with a reference voltage in stage 298. If such reference voltage is greater than the system output voltage, then there is applied a voltage to the a designated control windings in such polarity as to advance the firing of the magnetic amplifiers and thereby advance the triggering into conductivity of the silicon-controlled rectifiers. It is now seen that the polarity dot designations of the a designated control windings are such that an output from stage 298 which indicates a system output voltage less than the reference voltage increases the output of the magnetic amplifiers and a reference voltage that is less than the system output voltage provides a voltage from stage 298 which when applied to the magnetic amplifiers tend to decrease the output thereof. In this manner, voltage regulation is accomplished by the advancing or retarding of the firing of the magnetic amplifiers depending upon whether the system output voltage is below or above the desired reference level.

The restraining and inhibit circuit comprises a current transformer 290 and transistors 342 and 360. Transistor 342 comprises an emitter 344 connected to the junction 351 of the secondary windings of transformers 350, 352, and 354, a collector 346 connected to the upper terminals of the primary windings of transformers 327, 329 and 331 and a base 348 connected to the upper terminal of the secondary winding of current transformer 290 through resistors 356 and 358, the junction 357 being connected to a suitable source of positive potential through a resistor 359.

Similarly, transistor 360 comprises an emitter 362 connected to emitter 344, a base 361 connected to the lower terminal of current transformer 290 through resistors 364 and 366, and a collector 368 connected to the lower terminals of the primary windings of transformers 321, 323, and 325 respectively. The junction 345 of emitters 344 and 362 is connected to the midpoint on the secondary winding of current transformer 290, is connected to base 348 through the anode to cathode path of a diode 370 and is connected to base 361 through the anode to cathode path of a diode 372.

In the operation of the circuits comprising transistors 342 and 360, in the quiescent state, the base to emitter junctions of these transistors are so biased due to the connection to the B+ source that the transistors are normally conductive. Similarly, when positive current appears in either of the terminals of the secondary winding of current transformer 290, the transistor coupled to the particular terminal conducts.

However, in a situation where negative current appears either in the upper or lower terminals of the secondary winding of transformer 290, the conductivity in the transistor coupled to the terminal wherein the negative current appears is rendered nonconductive whereby the output at the collector of such transistor increases greatly in the positive direction.

It is realized that it is desired to prevent commutation from positive to negative controlled rectifiers and vice versa at a time when current is still flowing since commutation should occur at the zero current crossover point. Thus, in the event that the upper terminal of the secondary winding of trans-

former 290 is negative, a positive signal is applied to the primary windings of transformers 327, 329 and 331 which bucks the positive signal from the output of the magnetic amplifier. Likewise when negative current appears in the lower terminal of secondary winding of current transformer 290, a positive signal appears at the lower terminals of the primary windings of transformers 321, 323, and 325 respectively, which bucks the positive signals output from magnetic amplifiers 320, 322 and 324. The values of the circuit components in the restraining circuit are so chosen whereby these bucking signals are such as to open the circuit between the magnetic amplifier and the gating electrode of the silicon-controlled rectifier which it controls. With this arrangement, there is insured that no triggering of one group of similarly connected silicon controlled rectifiers can occur while current flowing in the other group of silicon-controlled rectifiers has not attained the zero crossover point, i.e., current is still flowing in the latter group.

As has been previously stated above, the outputs of the silicon-controlled rectifiers are applied across centertrapped series connected inductor 296 to drop thereacross the higher harmonics thereof and then filtered.

It is thus seen that during the positive half of a cycle of the system output current, rectifiers 264, 266 and 268 are being fired and during the negative half cycle of system output current, rectifiers 270, 272 and 274 are being fired. The interleavings of the outputs resulting from these repeated firings, their combining in inductor 296 and their filtering in filter 281 provides a sinusoidal output having the frequency of oscillator 280 no matter what indeterminate frequencies are being produced at the output of generator 250. The voltage regulator 298 functions to regulate the voltage at the output by advancing or retarding the firing of the magnetic amplifiers and consequently the advancing or retarding of the triggering into conduction of the silicon-controlled rectifiers. The restraining and inhibit circuits function to prevent switching of conduction from positive to negative controlled silicon-controlled rectifiers until current passes through the zero crossover point.

Static Exciter

(FIG. 9)

In FIG. 9 there is depicted a circuit suitable for use as the static exciter shown as stage 260 in FIGS. 2—4. In this circuit, there is included a three-phase saturable current-potential transformer 370 which comprises three sections 372, 374, and 376 of a current winding, three sections 378, 380 and 382 of a voltage winding and three sections 384, 386, and 388 of an output winding. The three sections of the current winding are connected between the outputs of the generator terminals and the lines which provide voltages e_1 , e_2 and e_3 . The three sections of the voltage winding are respectively connected across the three output lines and the three sections of the output winding are connected to a three phase full-wave rectifier generally designated by the numeral 390. The current-potential transformer also includes a DC control winding 392 which receives its excitation from the voltage regulator 261.

The sections of the voltage winding each have one end connected to ground and each section is connected to a corresponding output line through an inductor. Thus, section 382 is connected to a first line e_1 , through an inductor 394, section 380 is connected to a second line, e_2 , through an inductor 396 and section 378 is connected to a third line, e_3 , through an inductor 398. The other ends of inductors 394, 396 and 398 are respectively connected to ground through normally closed contacts GCR1, GCR2, and GCR3 associated with the generator control relay GCR.

The outputs of the sections of the output winding are applied to full-wave rectifier 390 comprising the bank of diodes poled as shown so that at the terminals of the rectifier there is provided a DC potential for energizing the field coil 258 of generator 250. The DC control winding 392 is connected to a

voltage regulator 261 whereby the excitation potential for field winding 258 is maintained at the proper amplitude to effect a relatively constant voltage amplitude at the output of the generator 250.

In the operation of the three-phase saturable current potential transformer, there are combined voltage and current quantities from the generator output in the current proportion and the magnitude of the resultant in field current in the generator is controlled by means of DC saturation. The transformer also functions as an impedance matching device between the generator output and the generator field. Inductors 394, 396 and 398 serve to shift the phase of the current derived from load current such that the field current which is proportional to the vector sum of the load currents has self-corrective action with respect to changes in load and power factor.

To improve the system accuracy, to take care of field temperature variations and to provide transient forcing, a saturating signal is supplied by the voltage regulator through the terminal of DC control winding 392. This saturating signal increases as the voltage tends to rise thus limiting the output of the exciter and thereby regulating the line voltage.

The current feedback feature enables the system to be self-sustaining in that it supplies excitation for and maintains short circuit current during any type or fault on the output side of the exciter current transformer. As will be seen in the description of the voltage regulator (FIG. 10), the auxiliary generator 254 of FIGS. 2-4 may be utilized for starting this system and for furnishing an AC supply to the magnetic amplifier in the voltage regulator. Such AC supply is available during all types of fault conditions to insure proper regulator action.

Included in the circuit of FIG. 9, is the generator control relay GCR which is utilized for turning the generator on and off. As has been previously described in connection with the protective panel, it is controlled in this panel by the generator control switch 310 shown in FIG. 5, lockout relay contacts 332 and normal speed relay contacts 314. When relay GCR is in the energized state, its normally closed contacts GCR1, GCR2 and GCR3 associated therewith assume the open position whereby the line voltage is applied to the particular sections of the potential winding of transformer through inductors 394, 396 and 398. When relay GCR is deenergized, the power supply to the potential winding is short circuited to ground thereby effectively deenergizing the generator since the AC output of the generator is then dropped to a small amount such as about one volt.

Voltage Regulator for Generator Output

(FIG. 10)

In FIG. 10, there is shown a circuit which may be suitably utilized as the voltage regulator 261 (FIGS. 2-4) for the static exciter of FIG. 9. The circuit essentially comprises a sensing circuit, a Zener diode reference, a single stage magnetic amplifier, stabilizing circuits and a transformer-rectifier for converting the power from auxiliary generator 254, i.e., the power from a permanent magnet generator, for example, to DC power.

In the circuit, the output from the auxiliary generator 254 is applied through transformer 400 and rectified in rectifier 402, the output of rectifier 402 being applied across the combination of a resistor 404 and the cathode to anode path of a Zener diode 406 to ground.

Autotransformers 408, 410 and 412 have one terminal thereof respectively connected to lines which provide the e_1 , e_2 , e_3 outputs respectively from generator 250 and their other terminals connected to ground. There are two taps on each of the autotransformers. The upper taps on the three transformers feed through rectifiers 414, 416 and 418 respectively and through the series combination of an inductor 420 and a resistor 422 whereby their smoothed out average value is impressed across a capacitor 424. The lower taps on the

transformers feed through rectifiers 426, 428 and 430 respectively directly to capacitor 424, the peak values fed through the rectifiers from the lower taps normally being just slightly less than the voltage from the inductor 420 and resistor 422. Thus, in normal operation, the average phase voltage impressed across capacitor 424 constitutes the signal to the reference voltage circuit comprising resistor 404 and Zener diode 406.

However, if because of unbalance, one phase voltage rises enough so that its peak value from a lower tap exceeds the average values from the higher taps, the highest phase voltage determines the signal to the reference circuit. From this, it is appreciated that average sensing in this circuit is utilized for normal operation but highest phase sensing takes over when unbalanced causes one phase voltage to rise above a chosen level. This can be understood when it is realized that it is possible for one or two phases to go to overvoltage when some abnormal condition causes reduced voltage on the other phase or phases. For example, a faulted feeder or line distribution circuit can cause such hazardous condition. Highest phase sensing reduces this hazard by maintaining the highest phase voltage at essentially a constant value.

In such highest amplitude phase takeover arrangement, average voltage sensing is provided by the voltage regulator during the small unbalance conditions that occur as result of unbalanced loads. If the voltage in any phase exceeds a chosen limit, then the sensing circuit of the voltage regulator automatically operates on the biases of the highest phase voltage.

Variable resistor 426 and parallel connected resistor 428 constitute a voltage divider which provides a portion of the output of the sensing circuit. Such portion is compared with the voltage across the Zener diode 406 to provide an error signal. Resistor 430 is utilized to determine the amount of current which flows as a result of a given voltage. Such current is fed through the DC control winding 432 of the magnetic amplifier and amplified in the magnetic amplifier 431 which also comprises control windings 438 and 440 and gate windings 434 and 436, the output of which control the saturable current potential transformer in the exciter (FIG. 9). The output of the magnetic amplifier at terminals D and C are respectively applied to corresponding terminals D and C of the control winding 392 in the static exciter (FIG. 9).

Capacitor 442 and resistors 430 and 426 comprise a lead network for effecting fast response with good stability. Control winding 438, capacitor 444, resistor 446 and diodes 448 and 450 provide the magnetic amplifier feedback circuit. The circuit consisting of the feedback network of the exciter from terminal D of winding 392 thereof and control winding 440 of magnetic amplifier 431 provides a field feedback circuit.

Voltage Regulator for Phase Output

(FIG. 11)

In FIG. 11, there is shown a voltage regulator suitable for use as a phase output voltage regulator such as stage 298 in FIGS. 2-4. In this circuit a system phase output such as the phase A output is applied through transformer 100 to a rectifier 102, the output of rectifier 102 being applied across a series arrangement of a resistor 104 and a reference diode (Zener 105).

The phase A output is also applied across a voltage divider comprising a resistor 106, a variable resistor 108 and a resistor 110. The voltage against which the output voltage is referenced is developed across diode 105. The error voltage when the output voltage either exceeds the reference or is less than the reference is developed across a resistor 112. Terminal 113 is connected to control winding 320a, and terminal 111 is connected to control winding 330a in FIGS. 6-8.

In the operation of the voltage regulator of FIG. 11 in conjunction with the a designated control windings in the magnetic amplifiers of FIGS. 6-8, it is seen that if the voltage at terminal 113 exceeds that at terminal 111, the direction of

current flow through the α designated control winding is such as to decrease the positive ampere turns therein the consequently to retard the firing of the magnetic amplifiers. Similarly, if the voltage at terminal 111 exceeds the voltage at terminal 113, the direction of current flow through the α designated control windings is such as to increase the positive ampere turns therein and thereby advancing the firing of the magnetic amplifiers.

The voltage from the bias circuit may be introduced between terminals 115 and 117 for load balancing in parallel systems and is further explained hereinbelow.

A voltage regulator such as stage 298 shown in FIGS. 2-4 and depicted in detail in FIG. 11 is utilized to regulate each system phase output.

Phase Displacement Feedback Correction

(FIG. 12)

In FIG. 12, there is shown a circuit which may be utilized as the phase displacement feedback correction stage 294 of FIGS. 2-4. In this circuit, for example if it is desired to correct for displacement of the phase A output, the phase B output, and the phase C output of the system are added vectorially in the primary winding 462 of a transformer 460. The secondary of transformer 460 comprises winding sections 464 and 466. Connected between the terminals of secondary winding sections 464 is a full-wave rectifier 468 having a resistance 470 connected thereacross as shown and a secondary winding 472 of a transformer 474. Connected between the terminals of secondary winding section 466 is a full wave rectifier 476 having a resistance 478 connected thereacross and a secondary winding 480 of transformer 474. The input to primary winding 482 of a transformer 474 is provided from the phase A output of the system. A resistor 486 is connected between the outputs of rectifiers 468 and 476.

In the operation of the circuit of FIG. 12, the circuit design is such that with a correct phase displacement between the three-phase outputs of the system, the average voltage across resistor 486 will be approximately zero. When such phase displacement is not balanced, i.e., 120° between phases, the outputs of rectifiers 468 and 476 are not equal and a net DC voltage appears across resistor 486. Such DC voltage may now be utilized to influence the direct current flowing in the control winding in a saturable reactor phase shift circuit or to vary the DC control in a phase shift circuit which includes an active device such as a transistor.

To correct for a phase displacement of the phase B output, the phase A and phase C outputs would be applied to primary winding 462 and the phase B voltage would be applied to winding 482 and to correct for the phase C output, the phase A and phase B outputs would be applied to winding 462 and the phase C voltage would be applied to winding 482. Accordingly, a phase displacement correction stage is desirable for each system phase output.

Normal Speed Relay Sensing Circuit

(FIG. 13)

In this figure there is shown a circuit which may be utilized as the normal speed sensing relay circuit 312 in the protective panel (FIG. 5). The input to the circuit at terminals H and K is provided from the output of the auxiliary generator 254 and is applied across the series combination of an inductor 490, an inductor 492 and a capacitor 494. The voltage appearing at the junction 491 of inductors 490 and 492 is applied to a full-wave rectifier 496, the output of full-wave rectifier 496 being connected in series with a resistor 498 and the control winding 502 of a magnetic amplifier 500.

The input applied from the output of the auxiliary generator is also applied through a resistor 504 to a full wave rectifier 506, the output of full-wave rectifier 506 being connected in series with a control winding 508 of magnetic amplifier 500.

The output from the auxiliary generator is also applied across the series arrangement of a first gate winding 510 of magnetic amplifier 500 and oppositely poled back to back diodes 512 and 514 and across the series arrangement of a second gate winding 516 of magnetic amplifier 500 and oppositely poled back to back diodes 518 and 520. Connected between the junction 513 of diodes 512 and 514, and the junction 519 of diodes 518 and 520 is a relay 522. Associated with relay 522 when it is utilized as the normal speed relay are normally open contacts 523 which correspond to contacts 314 in FIG. 5.

In the operation of the circuit of FIG. 13 as a normal speed sensing circuit, the current in control winding 502 is proportional to the applied voltage but varies appreciably as a function of frequency, such frequency dependence being effected by a tuned filter comprising inductors 490 and 492 and capacitor 494. The current in control winding 508 is proportional to the voltage applied to the circuit and is independent of frequency.

The direction of current flow in winding 508 is from terminal 507 to terminal 509 thereby providing positive ampere terms tending to increase the output of the magnetic amplifier. The direction of current flow in winding 502 is from terminal 503 to terminal 501 thereby providing negative ampere terms and tending to decrease the output of the amplifier. Since the voltage effects are balanced out due to the bucking effects of the control windings, it is seen that the circuit has an output when the current flowing in winding 508 exceeds the current flowing in winding 502. At a particular frequency which is chosen to be below the resonant frequency of inductors 490 and 492 and capacitor 494, the reactance of the tuned circuit is capacitive and quite high. Consequently, the quantity of current flowing in winding 502 will prevent an output from the circuit for energizing relay 522. As the frequency of the input approaches the resonant frequency of the tuned circuit, the reactance of the tuned circuit decreases whereby the current flow in winding 508 exceeds that in winding 502 and an output from the circuit energizes relay 522.

The exact frequency at which relay 522 is energized and deenergized is dependent primarily upon the values of resistors 504 and 498, inductors 490 and 492 and capacitor 494 as well as the number of turn in control windings 502 and 508. For slight changes in frequency setting, resistor 504 may be varied in value.

Over and Under-Frequency Sensing Circuit

(FIG. 14)

In this figure, a phase output such as the phase A output is applied to the primary winding 532 of a transformer 530. The in phase voltage appearing across secondary winding section 534 is applied through an inductor 536 and across the series combination of an inductor 538 and a capacitor 540. The voltage appearing across the series combination of inductor 538 and capacitor 540 is applied to a full-wave rectifier 542, a portion of the output of the rectifier being fed through a diode 544 and choke coil 546 to terminal 547 of a control winding 548 of a magnetic amplifier 550. The phase A output voltage is directly applied to gate windings 552 and 554 of amplifier 550.

The phase A voltage appearing in secondary winding section 556 is rectified in full-wave rectifier 558 and applied to terminal 561 of control winding 562 of magnetic amplifier 550 and is also applied to terminal 549 of control winding 548.

The phase A voltage appearing in secondary winding section 564 is applied through an inductor 566 and across the series arrangement of an inductor 568 and a capacitor 570. The voltage appearing across the series combination of inductor 568 and capacitor 570 is rectified in full-wave rectifier 572 and a portion of the rectified voltage appearing across resistor 574 is applied through a choke coil 576 to terminal 563 of control winding 562.

Inductors 536 and 538 and capacitor 540 comprise a tuned filter, their values being so chosen whereby at a frequency which is below a frequency slightly less than the desired frequency, the current flowing in control winding 548 from terminal 547 to terminal 549 due to the voltage appearing at junction 537 exceeds the current flowing from the terminal 549 to terminal 547 to increase the positive ampere turns and relay 578 is energized.

Inductors 566 and 568 and capacitor 570 comprise a tuned filter, their values being so chosen whereby at a frequency which is greater than the desired frequency, the current flowing in control winding 562 from terminals 561 to 563 due to the relatively low voltage appearing at junction 567 exceeds the current flowing from terminals 563 to 561 to increase the positive ampere turns. Thus, again in this situation, the output of the magnetic amplifier is increased and relay 578 is energized.

The bias voltage introduced at terminals L and M is utilized when there is parallel operation and is a DC voltage to bias the over and underfrequency relay. Such bias voltage is proportional to the difference between the real current supplied by the generator and the average of all the generators in the system. If one generator in a system comprising a plurality of generators is producing more or less than its share of the real current, such bias voltage has a polarity such that it adds to or subtracts from the voltage across rectifier 558 thereby making the over and underfrequency protection selective. The bias voltage is derived from stage 305 (FIGS. 2-4). Control winding 551 has applied thereto a fixed DC reference voltage to bias the magnetic amplifier off.

In connection with the circuit of FIG. 14, it is to be noted that underfrequency protection is required to prevent overheating of various types of load equipment. Transformers, magnetic amplifiers, and induction motors are examples of loads which cannot normally tolerate application of rated voltage at frequencies below their minimum design frequency. An overfrequency may also cause several types of damage.

There need be only one circuit such as that depicted in FIG. 14 for a system having a polyphase output since there is little if any likelihood of frequency deviations between the separate outputs. As explained hereinabove, the operation of the over and underfrequency relay causes the system to be disabled.

Overvoltage Relay Sensing Circuit

(FIG. 15)

In FIG. 15, there is shown a circuit suitable for use as the overvoltage sensing stage 324 of FIG. 5. In this circuit, AC potential for providing a reference voltage may be supplied from the auxiliary generator 254.

A reference voltage is provided in this circuit by means of a resistor 580, a transformer 582, a full-wave rectifier 584, a resistor 586 and a Zener diode 588. The input to the circuit is applied through resistor 580 and transformer 582 to rectifier 584 where it is full-wave rectified and filtered by capacitor 585 and developed across resistor 586 and Zener diode 588, the values of the resistors being so chosen that the voltage across Zener diode 588 is the desired reference voltage. The three phase outputs of the system are respectively applied through a resistor 590 and a diode 592, a resistor 594 and a diode 596, and a resistor 598 and a diode 600 to a common junction point and impressed across a capacitor 602. Accordingly, the DC voltage provided from the three phase half-wave rectifier circuit comprising diodes 592, 596 and 600 and resistors 590, 594, and 598 is essentially proportional to the highest phase voltage.

A portion of this voltage as determined by the selection of the values of resistors 604 and 606 which are connected across capacitor 602 is then compared with the reference voltage appearing at junction 587. The voltage from junction 587, when applied to a bias winding 610 of a magnetic amplifier 605 comprising control winding 608, bias winding 610 and

gate windings 612 and 614, tends to saturate the magnetic amplifier in the negative direction. Gate windings 612 and 614 are wound with a very large number of turns so that the AC flux excursion in the core of the amplifier is made very small compared to the saturation flux density of the core material.

The voltage appearing between the junction 607 of resistors 604 and 606 and junction 587 is applied to control winding 608 through diode 616, winding 608 having a resistor 618 connected thereacross. The magnetic amplifier power input is applied to gate windings 612 and 614 through a resistor 620 and a transformer 622.

The circuit of FIG. 15 also provides the time delay function as depicted in stage 326 of FIG. 5. Since bias winding 610 initially saturates the square-loop core material contained in the magnetic amplifier in the negative direction and gate windings 612 and 614 are wound with a very large number of turns so that the AC flux excursion in the core is made very small compared to the saturation flux density of the core material, accordingly, such flux excursion may be neglected in calculating the flux change caused by application of the voltage appearing between junction 607 and junction 587 to control winding 608, such voltage suitably being designated as E_c .

The time delay characteristics of the magnetic amplifier thus depend on the voltage E_c as follows:

$$E = N \frac{d\phi}{dt} \times 10^{-8} \quad (1)$$

$$E_c = N_c A_{Fe} \frac{dB}{dt} \times 10^{-8} \quad (2)$$

$$\int_{-B_s}^{+B_s} dB = \int_0^t \frac{E_c \times 10^8 dt}{N_c A_{Fe}} \quad (3)$$

$$\frac{2B_s N_c A_{Fe}}{10^8} = \int_0^t E_c dt = K \quad (4)$$

The above equations indicate that for the magnetic amplifier 605 with a saturation flux density B_s , control winding turns (N_c) and total cross sectional area of both cores equal to (A_{Fe}), a certain number of volt-seconds, K , are required to cause the flux density to change from $-B_s$ to $+B_s$, i.e., a total excursion of $2B_s$. At such time as the cores are saturated, the output voltage of the magnetic amplifier suddenly increases causing the relay 624 to be energized.

When the overvoltage is removed, thereby reducing the voltage, E_c , to zero, the output of the magnetic amplifier is quickly reduced to a very low value, thus, deenergizing relay 624. Bias winding 610 then causes the core of the amplifier to be reset to the negative saturation value. Complete resetting is normally accomplished within 1 to 2 seconds, after which time delay action can be repeated accurately.

The relay is energized when the voltage time integral of the voltage in excess of the ultimate trip voltage, (circuit long time energization voltage), is equal to a fixed number of volt-seconds. This may be expressed as:

$$K_{\text{volt-seconds}} = \int_0^t (E_{ac} - E_{ut}) dt \quad (5)$$

The ultimate energization voltage of relay 624 is determined primarily by the reference voltage at junction 587, the ratio of the output voltage from the line of the voltage across capacitor 602 and the value of resistors 604 and 606. The volt-second characteristic is then determined primarily by the characteristic of the core material, the number of turns on control winding 608 and the value of resistor 618.

Accordingly, the circuit of FIG. 15 senses the highest phase to neutral voltage by developing a sensing circuit which provides a DC voltage essentially proportional to the highest phase voltage, compares such DC voltage with an accurate reference voltage and applies the voltage signal thus obtained

which is proportional to the amount of overvoltage to a highly inductive magnetic amplifier which picks up a relay when this voltage signal has been applied for a sufficient time. The bias voltage signal applied to terminals N and O, is utilized in parallel operation to bias relay 624, thereby making the system selective on overvoltage protection.

Undervoltage Sensing Relay Circuit

(FIG. 16)

In FIG. 16, there is shown a circuit suitable for use as an undervoltage sensing circuit. In this circuit, the reference voltage is derived with an arrangement similar to that of the overvoltage sensing circuit of FIG. 15. Accordingly, the same designating numerals have been used for like elements in both circuits, the operation of such like elements being the same in each circuit. The output of the gate windings are rectified by diodes. The three-phase outputs respectively are fed through the series combination of a resistor 630 and a diode 632, the series combination of a resistor 634 and a diode 636 and the series combination of a resistor 638, and a diode 640. The output appearing at the cathodes of diodes 632, 636 and 640 are filtered respectively by the parallel combination of a resistor 641 and a capacitor 642, the parallel combination of a resistor 644 and a capacitor 646, and the parallel combination of a resistor 648 and a capacitor 650. Capacitor 652 is common to all three filters.

When any of the voltages appearing at the cathodes of diodes 632, 636 and 640 respectively are greater than the reference voltage, then such voltage is blocked by its associated reverse biased rectifier, viz, diodes 654, 656 or 658. If any of the voltages appearing at any of the cathodes of rectifiers 632, 636 or 640 respectively drop below the reference voltage, current flows from the reference voltage through the control winding 660 of a magnetic amplifier 661 and the output of the amplifier is reduced to a very low value whereby relay 662 is energized. When all three voltages appearing at the cathodes of diodes 632, 636 and 640 respectively are equal to or higher than the reference voltage, the output of the magnetic amplifier is increased and the relay is energized. Different settings of the undervoltage relay may be effected by the utilization of different values for resistors 630, 634 and 638.

The core material of magnetic amplifier 661 is initially saturated by bias winding 664 in the positive direction for repeatable performance.

The function of the bias voltage introduced at terminals X and Y is the same as that in the overvoltage sensing circuit of FIG. 15 and is utilized during parallel operation. To provide a fixed time delay, a thermal timer, as is well known in the art, may be utilized with the undervoltage sensing circuit to perform the fixed time delay function of stage 336 in FIG. 5.

It is to be noted that whereas in the overvoltage sensing circuit of FIG. 15, the relay is energized when an overvoltage occurs, in the circuit of FIG. 16, relay 662 is deenergized when the undervoltage is sensed. Thus, in the circuit of FIG. 5, it is to be realized that the relay of overvoltage sensing circuit 324 is normally deenergized whereas in the undervoltage sensing circuit 334, the relay is normally energized.

However, the fixed time delay stage 336, i.e., the thermal timer, for example, is energized to cause the energization of the lockout relay 328 (FIG. 5) when an undervoltage is sensed.

Real Load Division and Bias Circuit for Under and Overfrequency Circuits (FIG. 17)

In FIG. 17 there is shown a circuit substantially similar to the circuit of FIG. 12 which derives a real load division signal in a parallel arrangement of systems. In this circuit the phase A voltage is applied through the primary winding 201 of a transformer 200 to neutral. The secondary windings 202 and 203 are respectively in series arrangement with the secondary

windings 205 and 206 of a transformer 204 and rectifiers 208 and 210. The voltage developed across resistor 212 from the differential phase A current as measured by the secondary winding of a current transformer 214 and load division loop 308 is applied to primary winding 207 of transformer 204. The real load division signal is developed across resistor 211.

The voltage across resistor 211 is applied as a correction signal to the phase A voltage phase shifter in FIGS. 2-4.

To provide the real load division signal for the phase B output of the three-phase system, the phase B output would be tied to neutral through winding 201 and applied to current transformer 214, the voltage across resistor 211 being applied to the phase shifter for the phase B portion. To provide the real load division signal for the phase C output, the phase C output would be tied to neutral through winding 201 and applied to current transformer 214. Here again, the voltage across resistor 211 would be applied to the phase shifter for the phase C portion. Thus, where three like phase systems were arranged in parallel, nine circuits such as depicted in FIG. 17 would be required.

An identical circuit to that of FIG. 17, wherein the voltage across resistor 211 is also utilized as a bias signal for the under and overfrequency sensing circuits is included in the protective panel. Thus, in a parallel arrangement of three-phase systems, three such bias signals would also be required in the protective panels.

To provide the real load division signal for each reference oscillator in a parallel arrangement of a plurality of systems, the corresponding phase A, B, and C real load division signals are summed, the signal resulting from such summation being applied to the oscillator. To effect such summing the well-known passive resistive adder associated with a DC amplifier or an operational amplifier arranged as an adder can be utilized. The respective resultants of the summed real load signals of the other systems in the parallel arrangement are also applied to the corresponding oscillators.

Reactive Load Division and Bias Circuit for Over and Undervoltage Circuits (FIG. 17)

In a circuit which is similar to that of FIG. 17, the reactive load division circuit and the reactive bias circuit are obtained by supplying primary winding 201 of transformer 200 from the phase B to C voltage and current transformer 214 from the phase A output current. The voltage across resistor 211 would be applied to the phase A voltage regulator, as shown in FIG. 11, to provide equalization of reactive load. In a similar manner, phase C to A voltage would be applied to transformer 200 and phase B output current to transformer 215 to provide equalization of reactive load on phase B, and phase A to B voltage would be applied to transformer 200 and phase C output current to transformer 214 to provide equalization of reactive load on phase C. Similarly, the voltage across resistor 211 in the reactive bias circuit would be applied to the overvoltage and undervoltage protective circuits as shown in FIG. 15 and 16.

Differential Fault Protection Circuit

(FIG. 18)

The differential fault protection circuit shown in FIG. 18 effects deenergization of the generator 250 and opens the generator line contactor if any type of feeder short or generator winding short occurs.

Although the undervoltage protection circuit provides inherent protection against solid feeder faults, additional protection is provided by the circuit of this figure if intermittent or high impedance faults occur.

In this circuit, with the use of current transformers 230, 232 and 234 and current transformers 236, 328 and 240, the current flowing in the ground lead of each phase of the generator windings is compared with the current flowing out of the corresponding feeder wire.

Under normal conditions, currents in each corresponding pair of current transformers are equal. Under these conditions, currents in the current transformer secondary windings are equal and no potential difference exists between current transformer leads since the secondary windings are connected in a series siding loop. The induced currents flow around the loop and the resultant current through the protective circuit is essentially zero.

If a fault occurs on the feeders, part of the current flows through the fault and returns to the source. Therefore, it is sensed by one current transformer and not by the other transformer. The difference current in the current transformer secondary loop flows through the rectifier network generally designated by the numeral 242 and then through the parallel combination of current dividing resistor 243 and the operating coil of the differential fault protection relay 244.

While there have been described what are considered to be the preferred embodiments of this invention, it will be obvious to those skilled in the art that various changes and modifications may be made therein without departing from the invention and it is, therefore, aimed in the appended claims to cover all such changes and modifications as fall within the scope of the invention.

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

1. A frequency conversion system comprising a power source producing a voltage having an indeterminate varying frequency, a plurality of switching devices coupled to said power source to receive said voltage, said switching devices being actuated into conductivity upon the application of switching signals thereto, a reference frequency source, modulating means coupled to said power source and said reference frequency source, said modulating means including a plurality of control means, each of said control means being actuated into conduction at times controlled by the combined voltage outputs of said power source and said reference frequency source to produce said switching signals, means coupling said switching signals to each of said switching devices, and combining means coupled to said switching devices for combining the outputs therefrom to produce an output having the frequency of said reference frequency source.

2. A frequency conversion system comprising a power source producing an indeterminate varying frequency, a first group of switching devices respectively actuated into conductivity upon the application thereto of switching signals and the output from said power source of one polarity, a second group of switching devices respectively actuated into conductivity upon the application thereto of switching signals and the output from said power source of the opposite polarity, a reference frequency source, the frequency of said reference frequency source being less than the lowest frequency of said power source, modulating means coupled to said power source and said reference frequency source, said modulating means including a plurality of control means, each of said control means being actuated into conduction at times controlled by the combined outputs of said power source and said reference frequency source to produce said switching signals, means coupling each of said control means to corresponding ones of said switching devices, and combining means coupled to said switching devices to combine the outputs therefrom to produce a power output having the frequency of said reference frequency source.

3. A system as recited in claim 2 wherein each of said control means is a magnetic amplifier having a gate winding coupled to said power source and a control winding coupled to said reference frequency source.

4. A frequency conversion system comprising the indeterminate varying frequency power source having a number of balanced phase outputs, at least one frequency conversion means, each frequency conversion means comprising first and second groups of switching devices, each of the switching devices of said first group being actuated into conductivity

upon the application thereto of a switching signal and an output from said power source of one polarity, each of the switching devices of said second group being actuated into conductivity upon the application thereto of a switching signal and an output from said power source of the opposite polarity, a reference frequency source producing a number of phase displaced outputs equal to the number of frequency conversion means, the frequency of said reference frequency source being less than the lowest frequency of said power source, modulating means equal in number to the number of frequency conversion means, each modulating means being coupled to said power source and to the associated phase output reference frequency source, each of said modulating means being coupled to an associated frequency conversion means, each modulating means including a plurality of control means, each of said control means being actuated into conduction at times controlled by the combined outputs of said power source and said reference frequency source to produce said switching signals, means coupling each of said control means to corresponding ones switching devices, and means coupled to each of said frequency conversion means to combine the outputs of the switching devices therein so as to produce a number of balanced phase outputs equal to the number of frequency conversion means and having the frequency of said reference frequency source.

5. A system as recited in claim 4 wherein each of said control means is a magnetic amplifier having a gate winding coupled to one of the outputs of said power source and a control winding coupled to the associated output of said reference frequency source.

6. A frequency conversion system comprising an indeterminate varying frequency power source having a plurality of balanced phase outputs, a number of frequency conversion means equal to the number of system phase outputs desired, each frequency conversion means comprising first and second groups of switching devices, each of the switching devices of said first group being actuated into conductivity upon the application thereto of a switching signal and an output from said power source of one polarity, each of the switching devices of said second group being actuated into conductivity upon the application thereto of a switching signal and an output from said power source of the opposite polarity, a reference frequency source producing a number of phase displaced outputs equal to the number of system phase outputs desired, the frequency of said reference frequency source being less than the lowest frequency of said power source, modulating means equal in number to the number of system phase outputs desired, each modulating means being coupled to the outputs of said power source and the associated phase output of said reference frequency source, each modulating means being coupled to the associated frequency conversion means, said modulating means each including a number of control means equal to the number of switching devices within the associated frequency conversion means, each of said control means being actuated into conduction at times controlled by the combined outputs of said power source and said reference frequency source to produce said switching signals, means coupling each of said control means to corresponding ones of said switching devices, and combining means coupled to each frequency conversion means to combine the outputs of the switching devices therein so as to produce the desired number of balanced phase system outputs of the frequency of said reference frequency source.

7. A system as recited in claim 6 wherein each of said control means is a magnetic amplifier having a gate winding coupled to one of the outputs of said power source and a control winding coupled to the associated output of said reference frequency source.

8. A system as recited in claim 7 wherein each of said switching devices has an anode, a cathode, and a switching electrode, each switching device of said first group of switching devices has its anode coupled to one of the outputs from said power source, its cathode coupled to said combining

means, and its switching electrode coupled to the corresponding one of said control means in the associated modulating means, and each switching device of said second group of switching devices has its cathode coupled to one of the outputs from said power source, its anode coupled to said combining means, and its switching electrode coupled to the corresponding one of said control means in the associated modulating means.

9. In combination with a varying frequency power source having a number of balanced phase outputs, at least one frequency conversion means, each frequency conversion means comprising first and second groups of devices which are rendered conductive upon the supply of switching signals respectively thereto, each of said devices comprising an anode, a cathode, and a switching electrode, the anode of each of said first devices being coupled to one of said power source outputs, the cathode of each of said second devices being coupled to one of said power source outputs, a reference frequency source having a number of phase displaced outputs equal to the number of frequency conversion means, the frequency of said reference frequency source being less than the lowest frequency of the output from said power source, modulating means equal in number to the number of frequency conversion means, each modulating means being coupled to the outputs of said power source and the associated phase output of said reference frequency source to mix said power source outputs with the output of said reference frequency source, means for applying the respective outputs of said modulating means to the switching electrodes of the devices within corresponding frequency conversion means, combining means coupled to each frequency conversion means for combining the outputs of the devices therein to produce a number of balanced phase outputs equal to the number of frequency conversion means and having the frequency of said reference frequency source, and inhibit means responsive to the outputs from said combining means for supplying a signal to each of said modulating means for preventing the switching into conductivity of one group of said devices while current is flowing in the other group of said devices.

10. In combination with a varying frequency power source having a number of balanced phase outputs, at least one frequency conversion means, each frequency conversion means comprising first and second groups of silicon-controlled rectifiers, each of said silicon-controlled rectifiers comprising an anode, a cathode, a gate electrode, the anode of each of the silicon-controlled rectifiers in said first group being coupled to one of said power source outputs, the cathodes of each of the silicon-controlled rectifiers in said second group being coupled to one of said power source outputs, a reference frequency source having a number of phase displaced outputs equal to the number of frequency conversion means, the frequency of said reference frequency source being less than the lowest frequency of the outputs of said power source, modulating means equal in number to the number of frequency conversion means, each modulating means being coupled to the outputs of said power source and the associated phase output of said reference voltage source for mixing said power source outputs with the output from said reference frequency source, means for applying the respective outputs of each modulating means to the gate electrodes of the silicon-controlled rectifiers within the corresponding frequency conversion means, combining means coupled to each frequency conversion means for combining the outputs of the silicon-controlled rectifiers therein to provide a number of balanced phase outputs equal to the number of frequency conversion means and having the frequency of said reference frequency source, the cathodes of the silicon-controlled rectifiers in said first group and the anodes of the silicon-controlled rectifiers in said second group being coupled to said combining means, filter means coupled to the outputs of said combining means for removing those components having frequencies other than the frequency of said reference

frequency source, and inhibit means responsive to the current in the outputs from said combining means for preventing the switching into conductivity of one group of silicon-controlled rectifiers while current is still flowing in the other group of silicon-controlled rectifiers.

11. The combination defined in claim 10 wherein said reference frequency source comprises an oscillator having a determinable range of frequencies and a phase shifter for producing said phase displaced outputs from the output of said oscillator, and wherein there is further included sensing means in circuit with the outputs of said filter means for sensing an out-of-balance phase relationship between the outputs therefrom, the output of said sensing means being applied to said phase shifter as a correction signal.

12. The combination recited in claim 10 further including voltage regulating means responsive to the output of said filter means and coupled to said modulating means for comparing the voltage of the output of said filter means with the voltage of a predetermined value included in said regulating means, the output of said voltage regulating means being applied to said modulating means to control the time of the switching into conductivity of said silicon-controlled rectifiers.

13. The combination defined in claim 12 wherein each modulating means comprises a plurality of magnetic amplifiers, each of said magnetic amplifiers comprising a gate winding to which there is applied a power source output, a first control winding to which there is applied the output of said voltage regulating means and a second control winding to which there is applied the associated output of said reference frequency source, the output of a magnetic amplifier being applied to the gate electrode of an operatively associated silicon-controlled rectifier.

14. The combination defined in claim 13 wherein the output of a magnetic amplifier is applied to a gate electrode of a silicon-controlled rectifier through a transformer and wherein the output of said inhibit means is applied to these transformers in such polarities as to prevent the switching into conductivity of one of said groups of silicon-controlled rectifiers when the current in the outputs of said combining means is other than at the zero crossover point.

15. In combination, a rotary input source having an indeterminate variable speed, electrical generating means responsive to the application of said rotary input thereto for producing a number of balanced phase outputs of an indeterminate variable frequency directly proportional to said indeterminate variable speed, at least one frequency conversion means, each frequency conversion means comprising first and second groups of devices which are rendered conductive upon the supplying of switching signals respectively thereto, each of said devices comprising an anode, a cathode, and a switching electrode, the anode of each of the devices in said first group being coupled to one of the outputs of said electrical generating means, the cathode of each of the devices in said second group being coupled to one of the outputs of said generating means, a reference frequency source producing a number of phase displaced outputs equal to the number of frequency conversion means, the frequency of said reference frequency source being less than the lowest frequency of the outputs from said electrical generating means, modulating means equal in number to the number of frequency conversion means, each modulating means being coupled to the outputs of said generating means and the associated phase output of said reference frequency source for mixing said generating means outputs with the output of said reference frequency source, means for applying the respective outputs of said each modulating means to the switching electrodes of the devices within the corresponding frequency conversion means, combining means coupled to each frequency conversion means for combining the outputs of the devices therein to provide a number of balanced phase outputs equal to the number of frequency conversion means and having the frequency of said reference frequency source, and disabling means in circuit with said combining means and said electrical generating

means for disabling said combination when the voltage of an output of said combining means substantially differs from a selected voltage value and when the frequency of an output of said combining means substantially differs from the frequency of said reference frequency source.

16. The combination defined in claim 15 further including auxiliary electrical generating means operably associated with said rotary input source for providing operating supply voltages for said combination.

17. The combination defined in claim 16 wherein said auxiliary electrical generating means is a permanent magnet generator and wherein there is further included means responsive to the rotational speed of said rotary input source for controlling the electrical actuation of said combination, the last-recited means enabling said actuation only when said speed attains a predetermined level.

18. The combination defined in claim 15 wherein said disabling means comprises means coupled to the outputs of said combining means for disabling the operation of said combination when the voltage of one of the last-named outputs exceeds a first selected voltage and when the voltage of one of the last-named outputs is less than a second selected voltage.

19. The combination defined in claim 15 wherein said disabling means includes means coupled to the outputs of said combining means for disabling said combination when the frequency of one of the last-named outputs exceeds a first prescribed frequency and when the frequency of one of the last-named outputs is less than a second prescribed frequency.

20. The combination defined in claim 15 wherein said disabling means includes means coupled to said electrical generating means to disable said combination in response to a feeder fault in said electrical generating means.

21. In a multiple electrical generating system parallel arrangement, each system comprising a power source having an indeterminate varying frequency and having a number of balanced phase outputs, at least one frequency conversion means, each frequency conversion means comprising first and second groups of devices which are rendered conductive upon the supplying of switching signals respectively thereto, each of said devices comprising an anode, a cathode, and a switching electrode, the anode of each of the devices in said first group being coupled to one of the outputs of said power source, the cathodes of each of the devices in said second group being coupled to one of the outputs of said power source, a reference oscillator having a frequency which is less than the lowest frequency of the outputs of said power source, phase shifting means coupled to said oscillator for producing a number of phase displaced outputs equal to the number of frequency conversion means, modulating means equal in number to the number of frequency conversion means, each modulating means being coupled to the outputs of said power source and an associated output of said phase-shifting means for mixing said power source outputs with the phase-shifted output of said reference oscillator, means for applying the respective outputs of said each modulating means to the switching electrodes of the devices within the corresponding frequency conversion means, combining means coupled to each frequency conversion means for combining the outputs of the devices therein to provide a number of balanced phase outputs equal in number to said frequency conversion means and having the frequency of said reference oscillator, regulating means coupled to the output of each combining means and including a reference voltage and means for applying the difference between the voltage of an output of said combining means and said reference voltage as an input to the associated modulating means to control the time of switching of the devices in the corresponding frequency conversion means, means respectively coupled to each combining means and responsive to the outputs the corresponding combining means in the other systems in said parallel arrangement for deriving real load division control signals, means for applying one real load division signal as a correction signal to said phase shifting means, means respectively coupled to each combining means

and responsive to the outputs of corresponding combining means in the other systems in said parallel arrangement for deriving reactive load division signals, one reactive load division signal being applied as a correction signal to said regulating means.

22. The arrangement defined in claim 21 further including means for summing the real load division signals derived from the combining means in a system and for applying the resultant of said summed signals to said oscillator as a correction signal.

23. The arrangement defined in claim 21 further including protective means associated with each of said systems, said protective means being coupled to said combining means, said protective means comprising overvoltage means responsive to an output of said combining means having a voltage greater than a first selected value for disabling said system, undervoltage means responsive to an output of said combining means having a voltage less than a second selected value for disabling said system, overfrequency means responsive to an output of said combining means having a frequency greater than a first prescribed frequency for disabling said system, underfrequency means responsive to an output of said combining means having a frequency less than a second prescribed frequency for disabling said system, means responsive to the outputs of said combining means for deriving a first bias signal which is proportional to the difference between the reactive current supplied by the outputs of said combining means and the average of all the outputs of the combining means of said parallel arrangement, said first bias signal being applied to said overvoltage and undervoltage means and means responsive to the outputs of said combining means for deriving a second bias signal which is proportional to the difference between the real current supplied by the outputs of said combining means and the average of all the outputs of the combining means of said parallel arrangement, said second bias signal being applied to said overfrequency and underfrequency means.

24. The arrangement defined in claim 23 wherein means are coupled to each of said power sources for regulating the voltage of the output thereof.

25. In a multiple electrical generating system parallel arrangement, each system comprising a power source having an indeterminate varying frequency and having a plurality of balanced phase outputs, a number of frequency conversion means equal to the number of system phase outputs desired, each frequency conversion means comprising a first group of switching devices which are actuated into conductivity upon the application thereto of switching signals and the outputs from said power source of a positive polarity, and a second group of switching devices which are actuated into conductivity upon the application thereto of switching signals and the outputs from said power source of a negative polarity, a reference frequency source producing a number of phase displaced outputs equal to the number of systems phase outputs desired, the frequency of the reference frequency source being less than the lowest frequency of said power source, modulating means equal in number to the number of system phase outputs desired, each modulating means being coupled to the outputs of said power source and the associated phase output of said reference frequency source for mixing said power source outputs with the output from said reference frequency source, means for applying the respective outputs of each modulating means as switching signal to the switching devices in the corresponding frequency conversion means, combining means coupled to each frequency conversion means for combining the outputs of the switching devices therein to produce the desired number of balanced phase system outputs having the frequency of said reference frequency source, means respectively coupled to each combining means and responsive to the outputs of the other systems in said parallel arrangement for deriving a real load division signal, means for applying said real load division signal as a correction signal to control the time of switching the switching devices in said frequency conversion means,

means respectively in circuit with each combining means and responsive to the outputs of the other systems in said parallel arrangement for deriving a reactive load division signal, and means for applying said reactive load division signal as a correction signal to control the time of switching the switching devices in said frequency conversion means.

26. A frequency conversion system as recited in claim 2 further including inhibit means supplying a signal to said modulating means in response to the power output from said combining means to prevent the actuation into conductivity of one group of switching devices while current is flowing in the other group of said switching devices.

27. A frequency conversion system comprising an indeterminate varying frequency power source, a load, a number of frequency conversion means equal to the number of system phase outputs desired, each frequency conversion means comprising a switching device for each phase output of said power source of one polarity and a switching device for each phase output of said power source of the opposite polarity, each switching device being triggered into conduction to couple said power source to said load when said switching device is forward biased by the output of said power source and a switching signal is applied thereto, a reference frequency source producing a number of phase displaced outputs equal to the number of system phase outputs desired, a number of modulating means equal to the number of system phase outputs desired, each modulating means being coupled to receive the power source output and one phase output of said reference frequency source, each modulating means being coupled to one frequency conversion means, each modulating means including a control means for each switching device within the associated frequency conversion means, each control means within a given modulating means being coupled to the phase output of said power source that is coupled to its corresponding switching device and to the associated one phase output of said reference frequency source, each control means being triggered into conductivity by the half cycle of said power source output that forward biases the switching device coupled thereto to produce the switching signal for said switching device, the point of triggering within a half cycle being determined by the output from said reference frequency source, and means coupled to the switching devices in each frequency conversion means for combining the outputs therefrom to produce the desired number of balanced phase system output for said load having the frequency of said reference frequency source.

28. A frequency conversion system as recited in claim 27 wherein each control means is a magnetic amplifier having a gate winding coupled to one phase output of said power source and a control winding coupled to one phase output of said reference frequency source.

29. In an electrical power generating system including a system output terminal and a power source producing output power of varying frequency, converter apparatus for changing the source output power into system output power of predetermined lower, constant frequency, the converter apparatus comprising:

- means for generating a reference frequency signal having a constant frequency lower than the power source output frequency;
- means coupled to the power source and to the generating means for producing trigger pulses during successive half cycles of the power source output voltage in response to the reference signal and a portion of source output power;
- and controllable conductive means connected between the power source and the system output terminal and selectively controllable in response to applied trigger pulses to pass to the system output terminal portions of the positive half cycles of power source output voltage occurring during a period equal to one half cycle of the reference signal, and to pass to the system output terminal portions of the negative half cycles of power source output voltage

occurring during a period equal to the next half cycle of the reference signal.

30. In an electrical power generating system, converter apparatus as represented in claim 29 further including filtering means connected to the output of the controllable conductive means for smoothing said portions of the power source output voltage passed by the controllable conductive means.

31. In an electrical power generating system including a system output terminal and a power source producing output voltage and current of varying frequency, converter apparatus for changing the variable-frequency source output power into system output voltage and current equal in frequency to the lower, constant frequency of a reference signal, the converter apparatus comprising:

- means for generating a reference signal of constant frequency lower than the variable output frequency of the power source;
- and first and second controllable conductive means connected between the power source and the system output terminal and having a control terminal responsive to signals originated by the reference signal generating means for selectively conducting portions of the positive half cycles of power source output current during a period equal to one half cycle of the reference signal, and for conducting portions of the negative half cycles of power source output current during a period equal to the next half cycle of the reference signal.

32. In an electrical power generating system, converter apparatus as represented in claim 31 further comprising filtering means connected to receive the portions selectively conducted by the controllable conductive means for smoothing the waveform presented at said system output terminal.

33. In an electrical power generating system including a system output terminal and a power source producing output power of varying frequency, converter apparatus for changing the frequency of the source output power to a predetermined lower, constant frequency, the converter apparatus comprising:

- a first controllable, unidirectionally conductive device having a control terminal, an anode coupled to the power source, and a cathode;
- a second controllable, unidirectionally conductive device having a cathode coupled to the power source, a control terminal, and an anode;
- means for generating a reference signal at said predetermined lower, constant frequency;
- first means coupled to the power source, the reference signal generator, and the control terminal one of the first and second devices for controlling the latter to conduct during a period equal to one half cycle of the reference signal, a series of positive components of source power for use in forming the positive half cycles of the system output current;
- second means coupled to the power source, the reference signal generator, and the control terminal of the other of the first and second devices for controlling the latter to conduct, during a period equal to an alternate one half cycle of the reference signal, a series of negative components of source power for use in forming the negative half cycles of the system output current;
- and filtering means coupled to the cathode of the first device, the anode of the second device and the system output terminal for smoothing the positive and negative components of alternating power to form an approximate sine waveform of system output voltage and current equal in frequency to the reference signal.

34. In an electrical power generating system including a system output terminal and a power source producing output voltage and current of varying frequency, converter apparatus for changing the variable-frequency source output power into system output voltage and current equal in frequency to the lower, constant frequency of a reference signal, the converter apparatus comprising:

means for generating a reference signal of constant frequency lower than the variable output frequency of the power source;

means coupled to the power source and to the system output terminal for conducting portions at least of the positive half cycles of power source output current during a period equal to one half cycle of the reference signal, and for conducting portions at least of the negative half cycles of power source output current during a period equal to the next half cycle of the reference signal;

means coupled to the power source, to the reference signal generator, and to the conducting means for predetermining the conduction periods of the latter;

and means coupled to the conduction means and the system output terminal for synthesizing from the conducted portions of source output power continuous waveforms of system output voltage and current.

35. In an electrical power generating system including a system output terminal and a power source producing output voltage and current of varying frequency, converter apparatus for changing the variable-frequency source output power into system output voltage and current equal in frequency to the lower, constant frequency of a reference signal, the converter apparatus comprising:

means for generating a reference signal of constant frequency

cy lower than the variable output frequency of the power source;

means coupled to the power source and to the system output terminal for conducting portions at least of the positive half cycles of power source output current during a period equal to one half cycle of the reference signal, and for conducting portions at least of the negative half cycles of power source output current during a period equal to the next half cycle of the reference signal;

means coupled to the power source, to the reference signal generator, and to the conducting means for determining respective lengths of the conduction periods of the latter in accordance with a function at least approximating the desired waveform of the system output voltage and current;

and means coupled between the conduction means and the system output terminal for synthesizing from the conducted portions of source output power continuous waveforms of system output voltage and current.

36. In an electrical power generating system, converter apparatus as represented in claim 35 wherein the predetermining means comprises means for predetermining the respective lengths of the conduction periods of the conducting means in accordance with the amplitude of said reference signal.

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