

June 15, 1954

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2,681,418

STEAM GENERATOR COMBUSTION CONTROL

Filed July 14, 1951

6 Sheets-Sheet 1

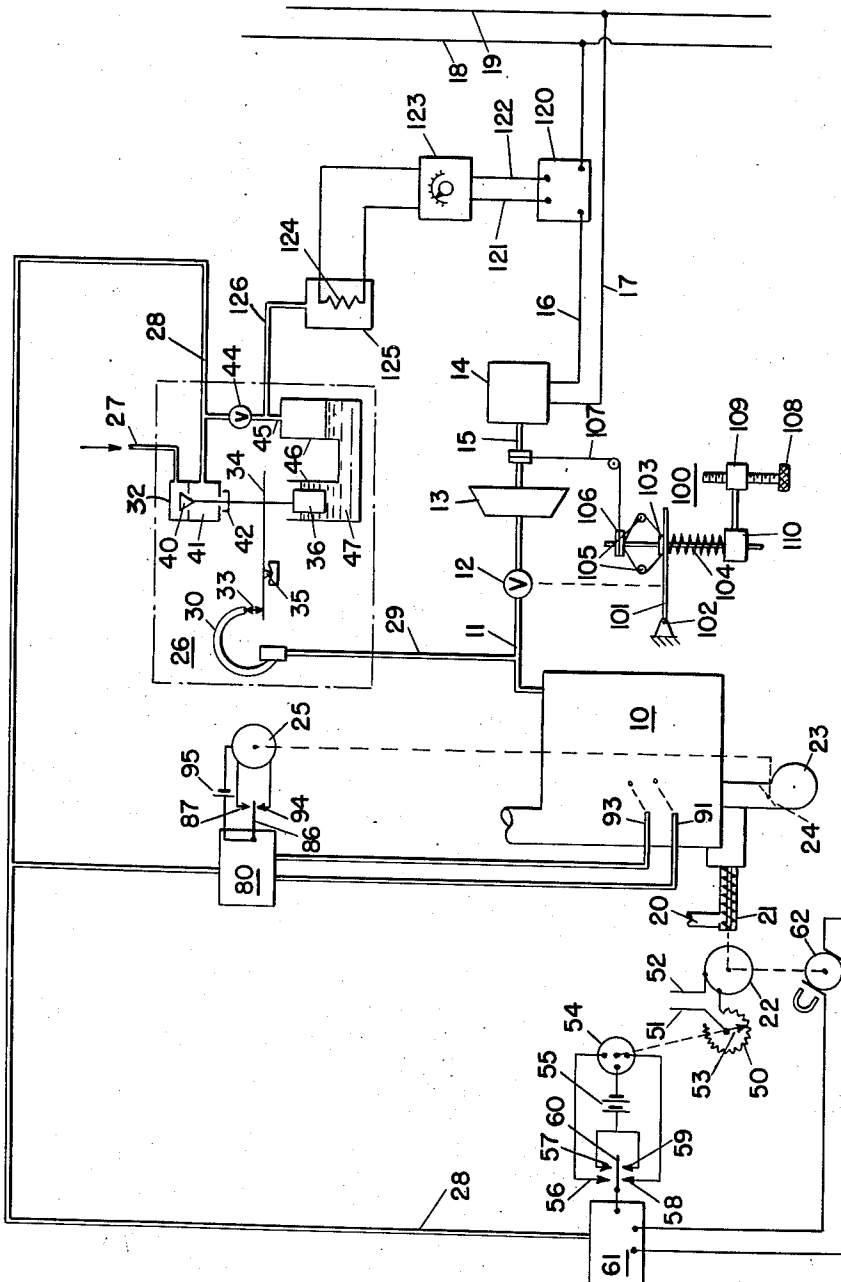


Fig. 1

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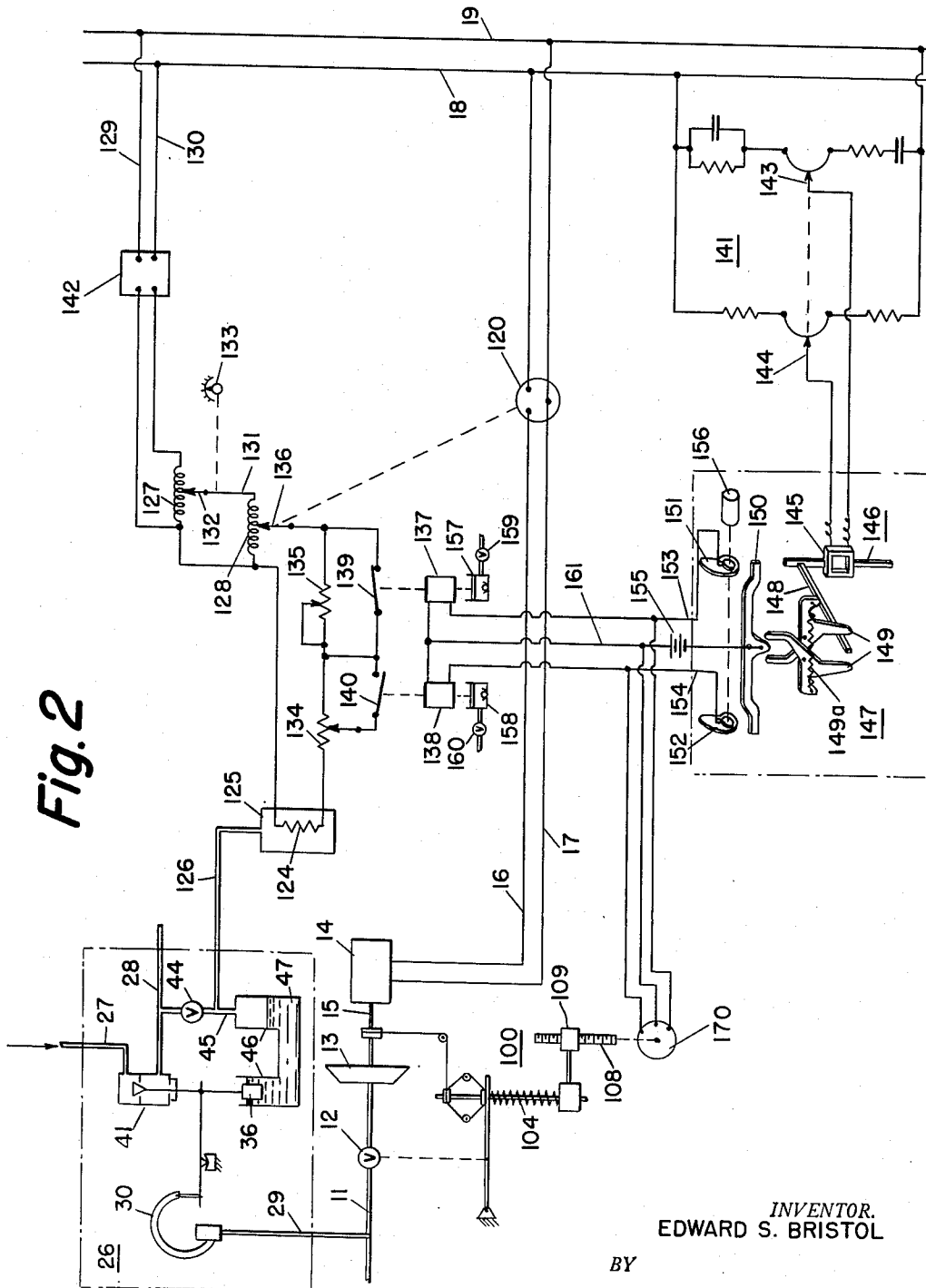
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STEAM GENERATOR COMBUSTION CONTROL

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6 Sheets-Sheet 2



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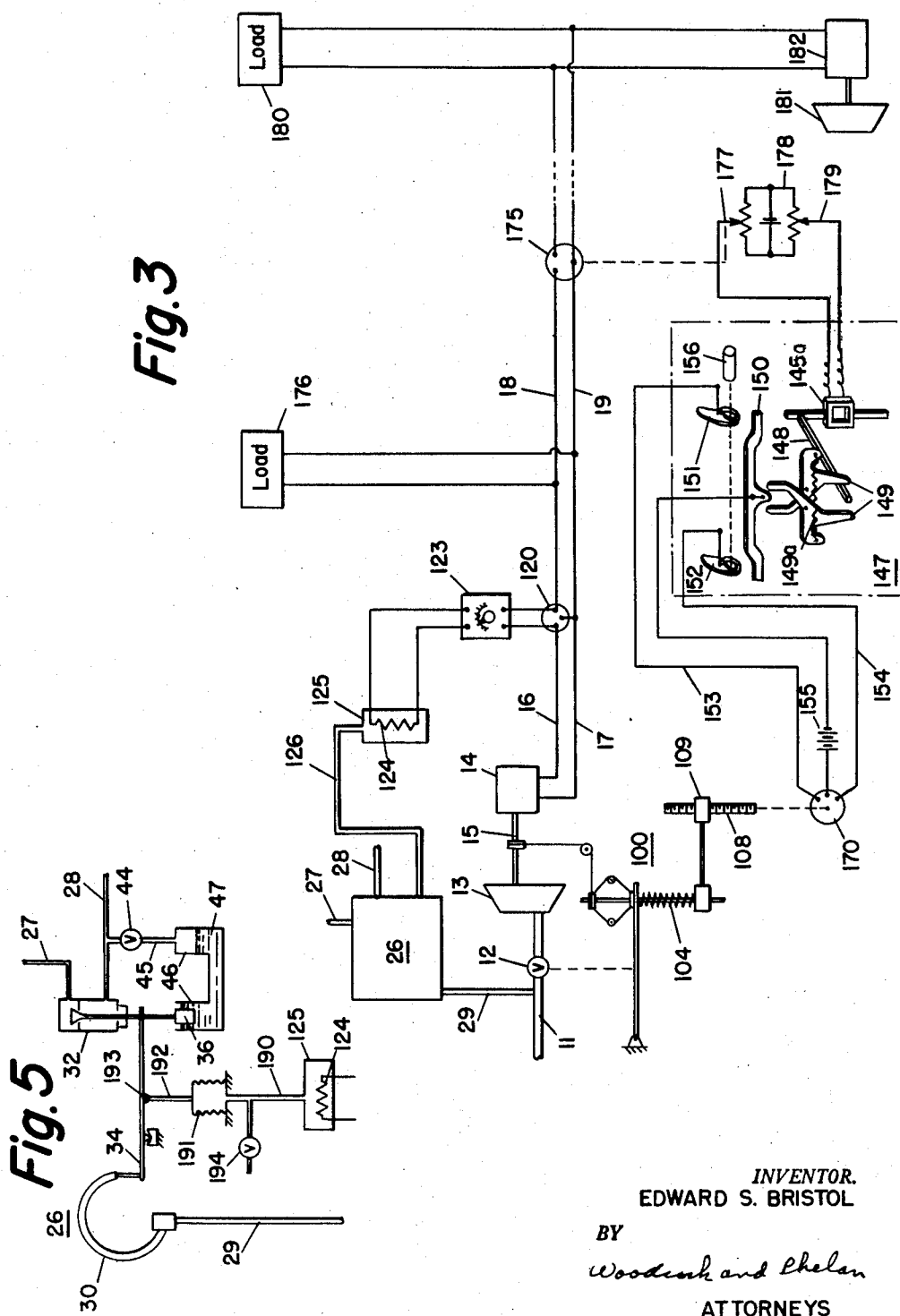
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STEAM GENERATOR COMBUSTION CONTROL

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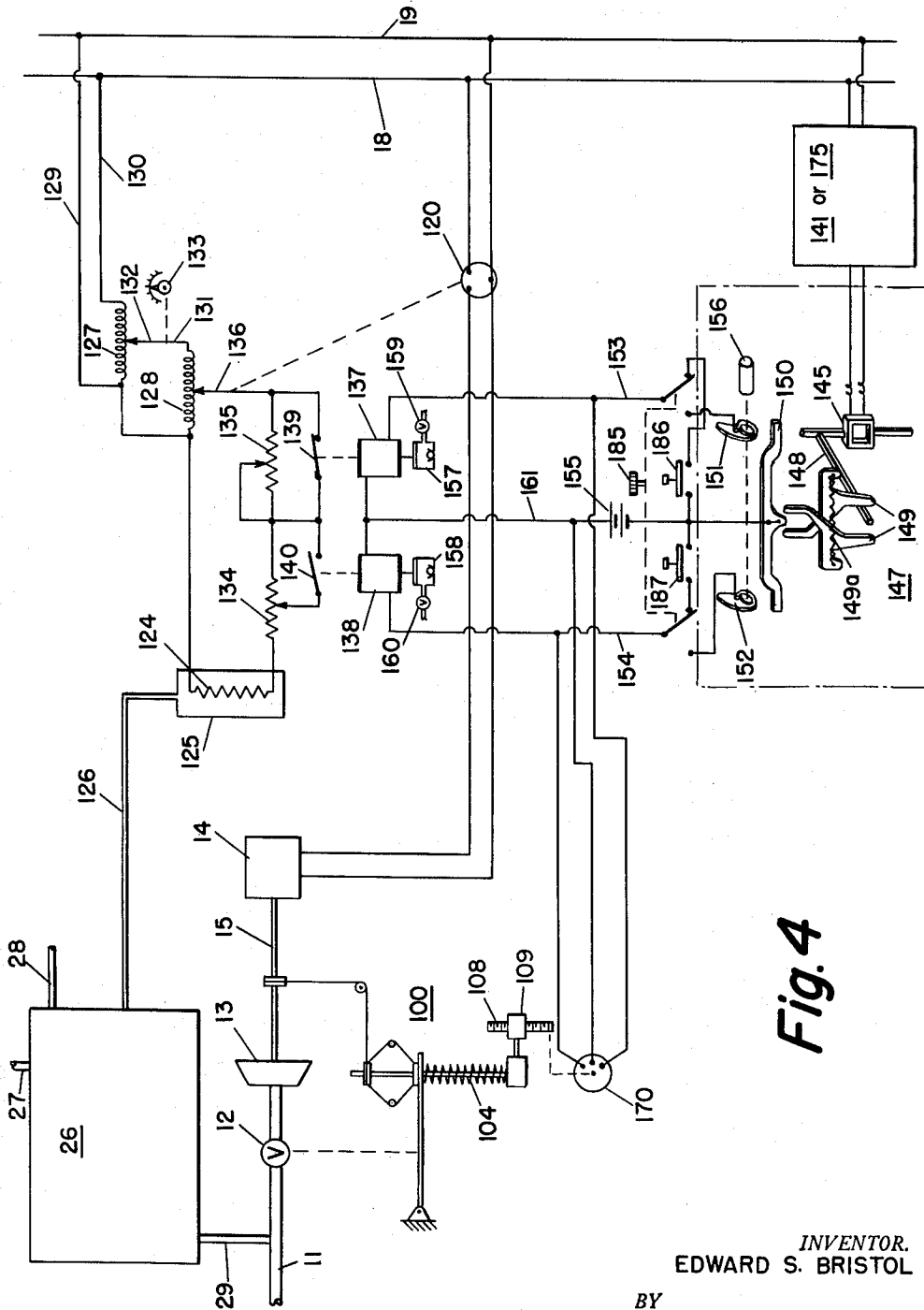


Fig. 4

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STEAM GENERATOR COMBUSTION CONTROL

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Fig. 7

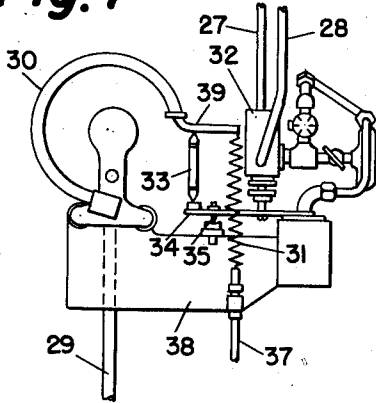


Fig. 9

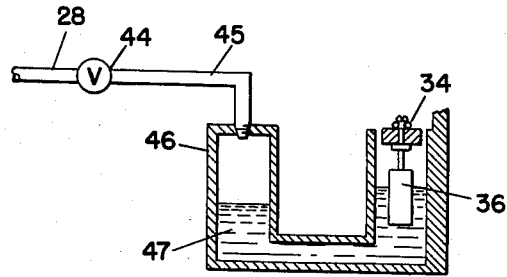


Fig. 8

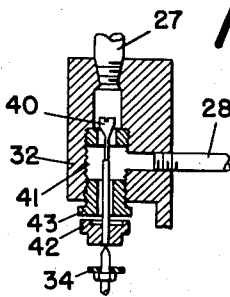


Fig. 10

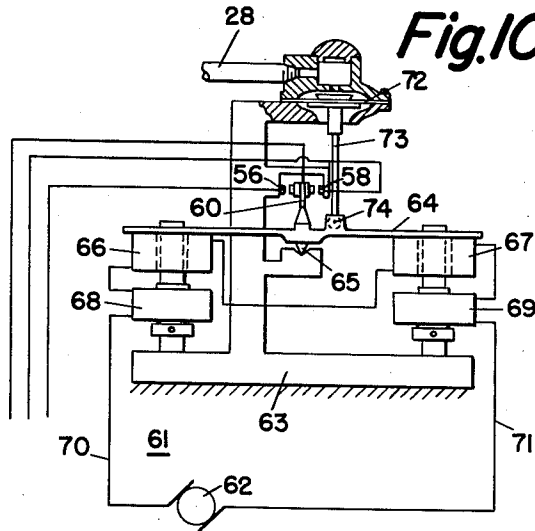
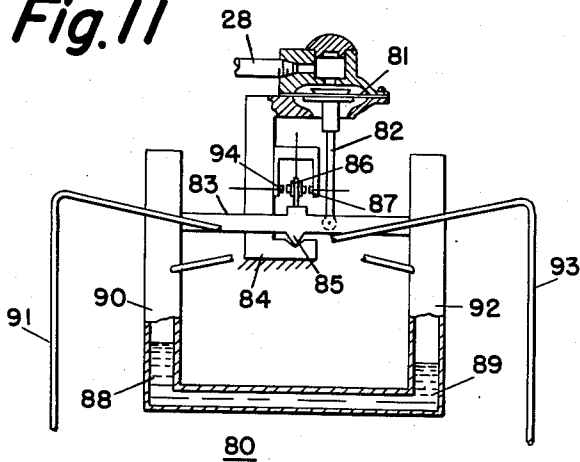


Fig. 11



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Application July 14, 1951, Serial No. 236,806

23 Claims. (Cl. 290-2)

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This invention relates to control systems for energy-translating devices such as a system in which a steam generator supplies steam to a turbine which in turn drives an electrical generator. In the past, such systems have been provided with a master control device which, in response to change in the pressure of the steam flowing to the turbine, has adjusted the rate of fuel supply and/or air to control the combustion or firing rate of the steam generator to vary the rate of heat-release in accordance with changes in load imposed on the turbine and generator. A characteristic of such a control system is the requirement that there be a change in the steam pressure before there is a modifying action on the heat-release within the steam generator. This characteristic has in many cases resulted in relatively large time delays following a change in load on the generator before the firing rate of the steam generator has been adjusted to compensate for the same.

It is an object of the present invention to introduce a modifying control action on the master control to anticipate changes in the load to be imposed upon the turbine-generator and to continue the modifying action in response to the extent of changes in the turbine-generator load in order that the heat generated within the steam generator will more closely and with minimum delay follow the load demand of the turbine-generator.

In a preferred form of the invention, the modifying control device may comprise an electrical heater disposed within a closed chamber flow-connected to a pneumatic force-balance system heretofore utilized in master controls of the pneumatic type. The electrical heater is energized in response to a variable which is indicative of the need for a change in the output of the generator and in response to a variable which is indicative of an actual load change on the generator. A corresponding adjustment is effected in the rate of heat generation within the steam generator by modifying the operation of the master control in accordance with these two variables. Specifically, the first variable may be a change in the frequency of an electrical load system where the frequency is to be restored to 60 cycles per second by increasing the output of a generator at a selected power station. At that power station, means are provided operable in accordance with the change in frequency to energize the electrical heater to vary the pressure of the pneumatic system immediately to change the rate of heat generation within the steam generator. The

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means for restoring frequency may adjust the governor of the turbine to increase the flow of steam thereto and thus to increase the output of the generator. Further in accordance with the invention, the resulting increase in the output of the generator is utilized as the second variable to increase the energization of said heater to continue or to further modify the pressure of said pneumatically-operable master control, and, hence, to maintain or make further modification of the rate of heat generation within the steam generator.

From the foregoing it will be seen that where there is a decrease in the system frequency, the generator at a particular power station will be operated with an increased output in a direction to return the system frequency to its desired value. Obviously, if the system frequency should increase above the predetermined value, the reverse cycle of operations will take place.

The present invention is applicable to a control system which functions to control the various units in manner described in my copending application Serial No. 151,650, filed March 24, 1950. However, the present invention is not limited in its utility to such a system.

The present invention particularly facilitates control of the generator output for the reason that the generator output can be varied as desired with accompanying prompt change in the steam generator output, without introduction of undesirable "hunting" or oscillation of the master control associated with the steam generator. More particularly, the master control operating in response only to changes in pressure at the inlet to the turbine can be adjusted to act relatively slowly for small pressure changes under relatively steady load conditions. Such response will be slow enough so that upon a change in pressure at the input of the turbine due to increased flow of steam, the heat input to the steam generator will be modified in a direction to return the input steam pressure for the turbine to a predetermined value without overshooting that value an amount sufficient to introduce oscillation into the control system. Furthermore, by connecting to the master control, and specifically in association with the reset element, a pressure chamber and providing within that chamber a pressure-varying device, provision may be made for modifying the action of the master control to change the heat generation within the steam generator to meet the new load condition to be imposed thereon. Preferably, the electrical load control may simultaneously modify

the action of the master control and the setting of the governor to change the output of the electrical generator. As before, the resulting change in the output of the electrical generator further modifies the master control by the action of the pressure chamber to insure the completion of the change in the rate of heat generation within the steam generator to meet the new heat condition imposed on the steam generator.

In addition to action cooperating with automatic load control as described hereinabove the present invention contemplates equivalent action for cooperating with manual load control.

It will be observed further that the control actions described are transitory in nature. This follows because both control actions modify the master controller by way of the reset device. It is further observed that the initially modifying action of the master control is immediate and the signal initiating the modification may be of very short duration. However, the modifying action as a whole is extended over a period of time adequate to assure a final adjustment of the heat generation within the steam generator to meet the new load condition imposed upon the electrical generator.

Further objects and advantages of the present invention will become apparent from the following detailed description taken in conjunction with the accompanying drawings which form an integral part of the present specification.

In the drawings, Fig. 1 is a diagrammatic representation of one form of the invention as applied to the control of the combustion rate of a steam generator or boiler.

Fig. 2 is a diagrammatic representation of a preferred embodiment of the invention which may be applied to the system such as that illustrated in Fig. 1.

Fig. 3 is a diagrammatic representation of an alternative embodiment of the invention similar to that shown in Fig. 2.

Fig. 4 is an alternative arrangement providing manual control for modifying the operating conditions for a system such as that illustrated in Fig. 2.

Fig. 5 is a diagrammatic illustration of an alternative arrangement for actuating the force-balance system of the master controller means shown in Figs. 1, 2, 3 and 4.

Fig. 6 is a diagrammatic representation of an alternative arrangement for modifying the operation of the master control means in response to variations in a load condition on the generator.

Figs. 7, 8 and 9 are detailed, diagrammatic views of the master control means shown schematically in Figs. 1 and 2.

Fig. 10 is a schematic representation of a preferred form of fuel feed control means, indicated in Fig. 1.

Fig. 11 is a schematic representation of a preferred form of the combustion-air control means, indicated in Fig. 1.

Referring now to the drawings and in particular to Fig. 1, there is schematically indicated a steam or vapor generator, such as boiler 10, adapted to supply thermal energy through steam line or header 11 and control valve 12 to an energy-converting means such as turbine 13. Turbine 13 is adapted to drive an electric generator 14 through drive shaft 15. The electrical output connections of generator 14 are diagrammatically represented by lines 16 and 17 which are respectively connected to power lines 18 and

19. It will of course be understood that these lines are entirely schematic since such a system as that to be described hereinafter is normally an alternating-current system of the three-wire/three-phase type.

The rate at which boiler 10 delivers thermal energy is normally controlled by the firing rate for the boiler. This firing rate may be controlled by any suitable means well understood in the art but for purposes of the present description, boiler 10 has been illustrated as having a fuel supply of solidified material which is adapted to be introduced through duct 20 and thence to the grate (not shown) of the boiler by means of a lead or feed screw 21. The rate at which fuel is thus supplied to the boiler is then controlled at least in part by regulation of the speed of drive motor 22 which is directly coupled to screw 21. Combustion air is supplied by means of blower 23 which is indicated to be of the centrifugal type.

The combustion rate is adapted to be controlled by means of damper 24 which is arranged to be positioned by a reversible drive motor 25.

As indicated hereinabove the fuel supply may be either fluid, whether gaseous or liquid, such as coke oven gas, natural gas, fuel oil and the like, or solidified material such as pulverized or lump coal, as illustrated in the embodiment shown in Fig. 1.

For the purpose of controlling the firing rate of boiler 10 and specifically in the present example to control the operation of fuel drive motor 22 and damper control motor 25, a master control means designated generally as 26 is arranged to regulate the pressure at which compressed air is supplied from any suitable source (not shown) through line 27. The purpose of this arrangement is to provide a resultant compressed air pressure known as loading-air pressure, as distinguished from combustion-air mentioned hereinbefore, which is a function of the steam pressure in supply line, or header, 11 to produce a fluid pressure in loading-air pressure line 28 which is a measure of the steam demand or load on boiler 10.

In order to more fully explain the operation of master control means 26 and its operation in metering compressed air from supply line 27 to loading air pressure line 28, reference is made to Figs. 7, 8 and 9 in addition to the diagrammatic illustration in Fig. 1. As shown in Figs. 1 and 7, pipe 29 connects supply line, or header, 11 to a Bourdon tube 30 which will expand under steam pressure against spring 31 to actuate a loading-air valve 32 through push rod 33 and lever 34 supported on a pivot 35. The downward force due to Bourdon tube 30 and spring 31 on lever 34 is opposed by a force due to air pressure acting on cup member 42. The force of spring 31 may be adjusted by any suitable screw means 37 by which spring 31 is anchored to frame member 38, thereby adjusting, as desired, the median point of pressure about which controller 26 operates. Bourdon tube 30 is connected to spring 31 through arm 39 which also provides means for transmitting force from the Bourdon tube to lever 34 through push rod 33.

Compressed air entering through pipe 27 is reduced in pressure and thereby converted to loading air pressure and applied to pipe 28 by valve means 32, as best seen in Fig. 8. Valve 32 is actuated by the cumulative effect of all forces applied to lever 34. One of these forces originates in Bourdon tube 30 and this force tends

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to produce air-loading pressure in pipe 28 having a pressure varying inversely with that in steam pipe 29, for example, when Bourdon tube 30 expands in response to an increase in steam pressure in pipe 29, as would result from a decrease in steam load, the righthand end of lever 34, as viewed in Fig. 7, is tilted downwardly by a small amount to close valve 40 thereby tending to reduce the air pressure in chamber 41 to which pipe 28 connects. Simultaneously cup member 42 moving with valve 40 permits air to leak at a slightly increased rate through passageway 43 so that loading air pressure in chamber 41 decreases in response to an increase in steam pressure in pipe 29 by the double effect of closing valve 40 and increasing the leakage rate through passageway 43 thereby producing a substantial decrease in loading air pressure with a very slight increase in steam pressure.

Conversely, upon a decrease in steam pressure, spring 31 predominates over the force from Bourdon tube 30 to open slightly valve 40 and simultaneously to reduce the leakage rate through passageway 43 by moving cup member 42 upwardly thereby increasing the air-loading pressure in chamber 41 and pipe 28. These changes in air-loading pressure are adapted to change the combustion rate of boiler 10 in a manner described hereinafter.

As thus far described the operation of master controller 26 would provide a definite air-loading pressure and therefore a definite combustion rate for each value of steam pressure. Such a system normally would be adjusted by screw 37 to maintain the desired steam pressure at the normal steam demand. However, any deviation from this normal demand would require a corresponding change in combustion rate which might be brought about by an appropriate change in air-loading pressure corresponding to a change in the steam pressure from the desired value. The automatic adjustment in combustion rate to maintain a constant steam pressure under varying steam or boiler load is known as reset action and may be produced by the following described reset means.

Referring now particularly to Fig. 9, it will be observed that loading air from pipe 28 is applied through valve 44 and pipe 45 to a chamber 46 at a rate depending upon the setting of valve 44 and the difference in pressures in lines 28 and 45. A U-shaped chamber 46 sealed by means of mercury 47 coats with float 36 supported on lever 34. The force due to the action of mercury 47 on float 36 acts on lever 34 in a direction to supplement the force on lever 34 due to Bourdon tube 30. Changes in loading air pressure in line 28 are slowly transmitted through valve 44 to U-tube chamber 46 to vary the mercury level at float 36. The resultant changes in upward force on float 36 act to replace the original initiating force change at Bourdon tube 30, causing steam pressure to return to a substantially constant value following a load change.

As mentioned hereinabove, an increase in steam demand on boiler 10 results in a somewhat decreased steam pressure which will increase the air-loading pressure in chamber 41. Further gradual increases in air-loading pressure as air from chamber 41 flows through valve 44 to chamber 46 and the consequent gradual increase in combustion rate of the boiler will continue until the steam pressure returns to its predetermined value which acting through Bourdon tube 30 causes the pressure in chamber 41

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to equal that in chamber 46. When these pressures are equal, reset action ceases, leaving the combustion rate properly adjusted for the increased demand as a result of the increased air-loading pressure. Upon a decrease in steam demand this action is reversed. The final net result of the reset action is to adjust the relationship of steam pressure to air-loading pressure to compensate for load variations. However, as indicated hereinbefore, a characteristic of such a control system is that in order for a modifying action to be effected upon the steam generator to vary the rate of heat release therefrom by varying the combustion rate, it is necessary that there be an initiating change in steam pressure. Accordingly, relatively long time delays are frequently experienced following a change in load on the electric generator connected to the steam turbine before the firing rate of the steam generator can be adjusted to supply the resulting increased load thereon and return steam pressure to its desired normal value. In accordance with the present invention, method and apparatus are provided for anticipating such changes in load prior to actual changes in steam load appearing at master control means 26.

As mentioned hereinbefore one of the controls of the combustion rate of boiler 10 is provided by governing the rate at which drive motor 22 moves feed or lead screw 21 to introduce fuel into the grate of the boiler. The control of the operating speed of motor 22 may be provided by rheostat 50 connected in series with a source of potential (not shown) through lines 51 and 52. By this arrangement more or less resistance may be connected in series with motor 22 by positioning the movable arm 53 which is connected directly to line 51. The positioning of arm 53 is controlled by drive motor means 54 which is connected so that it may be driven in either direction by battery 55 through either contactors 56 and 57 or contactors 58 and 59. Means are provided for directly connecting together either contacts 56 and 57 or contacts 58 and 59 by a movable contact arm 60 which is operated by a force-balance controller, designated generally as 61, and described more fully hereinafter as the fuel-feed controller means.

For a detailed description of fuel-feed controller means 61 reference is made to Fig. 10. The operation of controller 61 is in concurrent response, first, to the voltage output from a tachometer generator 62 which is directly driven by fuel-feed drive motor 22 and, second, to the air-loading pressure from master controller 26 as supplied through line 28. As particularly shown in Fig. 10 controller 61 in general comprises a frame member 63 providing a support for a lever arm 64 adapted to be supported on a pivot 65. Supported on the ends of lever arm 64 are a pair of movable solenoids 66 and 67 which coast with a pair of stationary solenoids 68 and 69, supported on frame member 63. Solenoids 66, 67, 68 and 69 are preferably connected in series through lines 70 and 71 to tachometer generator 62. However, solenoids 66 and 68 are connected so that their magnetic fields are additive whereas solenoids 67 and 69 are connected so that their magnetic fields are in opposition. To counterbalance the magnetic fields of the two opposed pairs of solenoids, an opposing torque is provided by diaphragm 72 and push rod 73 which is pivotally connected to the righthand side of lever arm 64 through pin 74. As shown, diaphragm member 72 is supported by the upper end of frame mem-

ber 63 and is adapted to be movable in response to changes in air-loading pressure supplied through line 23. Lever arm 64 likewise is arranged to carry movable conductor arm 60, shown diagrammatically in Fig. 1, which is arranged to make contact alternatively with the stationary contacts 56 and 58. Contacts 57 and 59 to which contacts 56 and 58 respectively are connected by arm 60 are mounted directly behind contacts 56 and 58 as seen in Fig. 10. From the foregoing description it is apparent that motor 54 may be operated to position movable arm 53 of rheostat 50 and thereby control the speed of fuel-feed motor 22 in response to action of controller 61. In this way, motor 54 will be operated whenever there is a departure from a balanced relationship between air-loading pressure and fuel flow and such operation will be in a direction to restore such a balanced relationship.

For the purpose of maintaining the air flow through boiler 10 in a balanced relationship to the air-loading pressure and thereby further control the combustion rate of the furnace and the rate of energy release by boiler 10, provision is made for controlling the opening of damper 24 by means of reversible motor 25. The control of motor 25 in accordance with the desired relationship is accomplished by controller 30 which is shown in greater detail in Fig. 11. As there shown, loading air from master controller means 26 may be applied through pipe 23 to diaphragm 81 to apply a clockwise torque through push rod 82 to lever arm 83 which is pivotally supported upon a stationary frame member 84 by means of pivot 85. This clockwise torque alone would cause center contact 86 supported by lever arm 83 to engage contact 87 and energize motor 25 through any suitable power source, such as battery 95. However, counterbalancing the above-mentioned clockwise torque is a counterclockwise torque due to the unbalance of a pair of liquid columns 88 and 89 which in magnitude and direction depends on the air flow through boiler 10. This is accomplished by the connection of chamber 90 above liquid column 88 to draft tap 91 and chamber 92 above liquid column 89 to draft tap 93 which being downstream of draft tap 91 has a lower pressure and consequently the greater height and weight of liquid.

When the above-mentioned counterclockwise and clockwise torques are equal so that center contact 86 assumes a position intermediate contacts 87 and 94, motor 25 will not be energized and damper 24 will remain in its previously set position. However, upon an increase in air-loading pressure in line 23 indicating a decrease in steam pressure and hence an increase in steam load, diaphragm 81 will operate through push rod 82 and lever 83 to make contact between center contact 86 and contact 87 to energize motor 25 so that damper 24 will be opened. Upon an increase in steam pressure the reverse cycle of operation will be effected. However, such action will be only sufficient to establish the predetermined relationship between air-loading pressure and air flow.

Further control of the system shown in Fig. 1 is provided for a purpose well understood in the governing of prime movers of the type illustrated by turbine 13. A fly ball governor mechanism 100 is schematically shown as being adapted to control the operation of valve 12 through the operation of lever 101 having one end pivotally supported by any convenient means, such as pin 102, while the opposite end carries a weight member

103. Weight member 103 is arranged to be moved in opposite directions by biasing spring 104 and fly balls 105 which are shown as being rotatable through a conventional pulley 106 and belt 107 which in turn are driven by shaft 15 which interconnects turbine 13 and generator 14. As indicated in Fig. 1 means may be provided manually for adjusting the speed of turbine 13 for any existing load. This manual adjustment may be made by a mechanical set screw 108 which is arranged to position a traveling nut 109 interconnected with a supporting member 110 to which one end of biasing spring 104 is attached.

As distinguished from previously known control means for regulating the rate of energy release from boiler 10 to maintain the required output from the energy-converting means, comprising turbine 13 and electrical generator 14, the present invention provides method and apparatus for anticipating the changes in electrical load conditions, which are accompanied by changes in the steam load on the boiler, by developing a quantity which has a predetermined relationship to the change in electrical load. In the embodiment illustrated in Fig. 1, this modifying control quantity is arranged to be developed by an electrical load responsive means 120 which may be a current transformer or a recording ammeter, connected across one of the output lines such as line 16, adapted to produce an output voltage or current on lines 121 and 122 which is proportional to the current flow in line 16. The potential or current developed in lines 121 and 122 may be connected through a manually controllable potentiometer or variable transformer 123 for a purpose to be described hereinafter. The net potential output of potentiometer or transformer 123 is then arranged to be applied to an electrical heater element 124 which is preferably positioned within a chamber 125. Chamber 125 is arranged to be interconnected through line 126 to line 45 which connects directly with chamber 46 of the reset portion of master controller 26. By the arrangement just described, the pressure in chamber 125, which will normally contain air, will vary in accordance with the differences in the square of the current flowing in heater element 124. The current in heater element 124 will be arranged of course to be proportional to the current flow in output line 16 directly connected to electrical generator 14. Accordingly, when a load change is experienced in lines 13 and 19 this load will be reflected on electrical generator 14 and cause an increase in current flow through line 16. This increase in electric load likewise will be reflected immediately by a change in pressure in chamber 125 which through line 126 will increase the pressure in chamber 46 to raise the level of the mercury column and thereby tend to raise float 36 to open valve 40 and immediately increase the loading air pressure in line 23. Accordingly, this change in loading air pressure being effected by changes in the electric load as distinguished from the relatively slow change in steam load provides an anticipating operation in the combustion rate of boiler 10. The resulting modifying action which occurs as a result of change in the output of generator 14 is of great importance. The change in pressure in chamber 125 due to the heater 124 applies to the force-balance system, including the element or lever 34, a control quantity or modifying force to cause it to move or rotate in a direction to augment the change in position of the cup 42 and of valve 40 which would otherwise oc-

cur by a corresponding change in pressure in the Bourdon tube 30. The change in the position of element 34 due to the pressure produced by the heater 124 occurs earlier and, hence, anticipates the change which otherwise would occur as a result of change in pressure at Bourdon tube 30. The adjustment resulting solely from the development of pressure in chamber 125 due to the heater 124 will in many cases be adequate to readjust the rate of generation of heat in boiler 10 to anticipate and to compensate for the change in load on the generator 14.

The rheostat 50, determining the rate of fuel delivery to the boiler 10, and the damper 24 for combustion air, are thus moved to new positions to meet the new load condition on the generator 14 by reason of the new level of pressure established in line 28. A continued steady-state operation of the electrical generator 14 at the new load does not result in a continued rise in the pressure in chamber 125. If the electrical load has increased, the heat generated by the heater 124, of course, has increased. So have the radiation losses from chamber 125. There is attained a balance between the increased radiation losses and the increased generation of heat in chamber 125. With thermal equilibrium thereby established, there is no further change in pressure in chamber 125 due solely to the generation of heat by heater 124. However, the master controller 26 at all times retains its primary control function in regulating the combustion rate for boiler 10, and with any change in position of element or lever 34 due to the Bourdon tube 30, the pressure in line 23 will be adjusted, and the pressure in chambers 46 and 125 will be correspondingly changed through air leakage by way of restriction provided by valve 44.

Referring now to Fig. 2 wherein there is shown a preferred embodiment of the invention employing the output load responsive control quantity described in Fig. 1, as well as a further anticipating action for modifying the operation of said electric load responsive apparatus. Similar numbers have been used to designate similar elements described in connection with Fig. 1. In the present embodiment, however, heater element 124 disposed in chamber 125 is preferably energized from load lines or tie lines 18 and 19 through a pair of potential varying transformers 127 and 128. As indicated, transformer 127 is connected to voltage regulator 142 and through lines 129 and 130 to lines 18 and 19. Transformer 128 has one end of its coil connected through line 131 to the variable tap 132 of transformer 127. Variable tap 132 is preferably controllable by manual adjusting means such as dial 133. The opposite side of transformer 128 is connected directly to voltage regulator 142 as is one side of heater means 124. The opposite side of heater means 124 is preferably connected through a pair of series resistors 134 and 135 to the adjustable tap 136 of transformer 128. In the present embodiment, heater means 124 is arranged to be energized in response to the load on electrical generator 14 by placing the operation of adjustable tap 136 under the control of load responsive means 120, which in the present instance is indicated as a wattmeter appropriately connected to lines 16 and 17. By the arrangement just described, it will be apparent that heater means 124 will be energized in a manner somewhat similar to that described in connection with Fig. 1. However, as particularly distinguished from the embodiment shown in Fig. 1, control of heater element 124 is

further subject to modification by the operation of relays 137 and 138 which are arranged for selectively inserting and removing resistors 134 and 135 in series connection with the heater means. This action is accomplished by means of relay 137 which has a normally closed contact 139 providing a shunt path around resistor 135 and relay 138 which has a normally open contact 140 arranged to provide a shunt path around at least a portion of resistor 134. Operation of the coils of relays 137 and 138 is primarily under control of a power-line load responsive means, such as frequency bridge 141, which is connected across the tie-line or power-supply lines 18 and 19. While any suitable frequency responsive bridging may be utilized for this purpose, bridge 141 is similar in construction and operation to that described in Patent 1,751,538 to Wunsch and reference is made to the Wunsch patent for a complete description of the circuit and operation of said bridge. However, as diagrammatically shown, two of the common or junction points of the bridge are directly connected to the power line as represented by lines 18 and 19 whose frequency is to be measured. The opposite junction points of the bridge are preferably connected through a pair of movable contacts 143 and 144 to coil 145 of a galvanometer 146.

Galvanometer 146 is illustrated as the control element of a measuring instrument, or mechanical relay, designated generally as 147. The mechanical relay, or pulse-producing device, 147 diagrammatically shown in Fig. 2 is in operation quite similar to the one described and shown in Fig. 6 of Doyle Reissue Patent No. 20,548. However, the mechanical relay illustrated in the present case is based upon the arrangement shown in Squibb Patent No. 1,935,732. As diagrammatically illustrated in Fig. 2, deflection of galvanometer coil 145 in one direction or the other positions pointer 148 between a pair of feeler members 149. Feeler members 149, under control of a spring 149a and a cam (not shown), in turn are arranged to deflect a lever 150 pivotally movable about its center and serving as an electrical conductor to make contact with a pair of constantly rotating cams 151 and 152 driven by any suitable driving means, such as synchronous motor 156. Each of the cams 151, 152 is provided with a suitable collector ring and brush arrangement providing connection from said cams to lines 153 and 154, respectively. As shown, line 153 is connected to one side of the operating coil of relay 137 while line 154 is similarly connected to the operating coil of relay 138. The desired energization of relays 137 and 138 under control of mechanical relay means 147 is provided by any suitable power source, such as battery 155, which has one side connected in common to the coils of relays 137 and 138 and the opposite side connected to lever 150.

As indicated, time delay means may be provided for the deenergization of relays 137 and 138 by suitable dash pots 157 and 158, each represented as comprising a piston connected to the armatures of relays 137 and 138, respectively, and a chamber or cylinder having a ball-check valve so arranged that the piston may rise rapidly through the cylinder but the downward motion is retarded by air pressure within the chamber closing the ball-check valve and leaking through valve members 159 and 160, respectively.

In addition to the control of relays 137 and 138 in response to changes in a tie-line load condition, as detected by the power-line responsive

means 141, provision is made for automatically controlling the biasing of spring 104 of the fly-ball governor 100. This is accomplished by controlling the position of nut 109 by operating drive screw 108 through a reversible drive motor 170. Motor 170 is connected to battery 155 by lines 153 and 154 as well as common connecting line 161. This arrangement for varying the tension on spring 104 of the fly-ball governor provides a regulating action directly on the turbine in response to the same tie-line load condition, such as frequency, which is adapted to modify the operation of the master control means.

Operation of the embodiment shown in Fig. 2 is similar to that described in conjunction with Fig. 1. The air-loading pressure developed in line 20 by master controller 26 is adapted to be modified in substantially the same way by varying the pressure developed in chamber 125 as a result of variations in heat developed by heater means 124.

As mentioned hereinabove, heater means 124 is primarily controlled by electrical generator output responsive means 120, which in the present embodiment is shown as a wattmeter. Wattmeter 120 is arranged to position the adjustable tap 130 of input transformer 128. By this arrangement an increase in load on lines 16 and 17 causes the current supplied to heater 124 to increase in proportion to the change in load. Similarly, a decrease in load on generator 14 correspondingly decreases the heater current in proportion thereto. As likewise mentioned above, the changes in pressure in chamber 125 due to changes in output of heater 124 are transient in nature and are adapted to increase or decrease the pressure applied to chamber 46 of the mercury column arrangement of master controller 26 only in response to changes in load on the electrical generator.

As contemplated by the present invention the heater current may be directly proportional to electric generator current or load and the heat output of element 124 will thus be proportional to the square of the generator current or load. Such an output is well adapted for use with a master controller maintaining an air-loading pressure which is proportional to the square of boiler steam flow as commonly employed in the art of controlling boiler furnaces. Thus a control action is introduced by the master controller which regulates the flow of fuel and combustion air (the rate of energy generation) in accordance with a root, such as the square root, of the change in potential of the energy as reflected by a change in steam pressure while the element 124 introduces a modifying action into the master controller varying with the square of the generator load and produces a change in the flow of fuel and combustion air proportional to the change in generator load. Thus heater 124 introduces into the regulating means, master controller 26, a modifying action of a non-linear character. In this way, for equal increments of change in the output of generator 14, the air-loading pressure will be changed by unequal increments, but the rate of energy generation will be changed by equal increments. The inequality between increments of change in the loading pressure will increase with increasing load on the steam-consuming device comprising the turbine and electrical generator and will decrease with decreasing load.

Control of the current flow through heater means 124 may be additionally modified in re-

sponse to a change in load conditions occurring in the interconnected power system which is represented by power lines 18 and 19. This change in load condition may cause a decrease in frequency of the interconnected power system when a greater load is applied thereto. Such a drop in frequency from, for example, 60 cycles per second to 59 cycles per second, in the embodiment shown in Fig. 2, will cause a deflection of galvanometer coil 145 in a direction to move its pointer toward the right of Fig. 2. The pointer is then clamped in its deflected position and the feelers 143 released in manner fully described in Squibb Patent No. 1,935,732. The spring 149a then rotates the lower ends of the feelers toward the galvanometer pointer. The righthand end of the feeler initially approached by the pointer first engages it and comes to standstill. As the other feeler moves toward the pointer, its upper end engages a projection or pin on arm 150 to rotate it about its pivotal support by an amount, or through an arc, the length of which is dependent upon the extent of deviation of the frequency from the 60 cycle normal value to be maintained as reflected by the extent of deflection of the galvanometer pointer.

With the pointer 143 midway of the feelers, or with the lever 150 horizontal, neither of cams 151 and 152 completes circuits for relays 137 and 138.

However, with the lever 150 in its deflected position as described, an energizing circuit for relay 138 will be completed as soon as cam 152 engages arm 150. That circuit will be maintained closed for a time interval dependent upon the extent of deviation from the desired value of the quantity, frequency, under control. The length of the energization time for relay 138 can be varied by changing the shape of cam 152, a shape providing a proportionally longer time with greater deviation from the predetermined frequency being illustrated for both of the cams.

After the arm 150 is returned to its initial horizontal position, the pointer 143 is released by cam means, also fully described in said Squibb patent, to respond to any change in unbalance of the bridge. The foregoing operations continue until the frequency is restored to its desired value. Then the galvanometer pointer 143 will remain in the mid-position between the feelers, and arm 150 will not be deflected by the feelers 143. As soon as relay 138 is energized its contact 140 is closed to apply a higher potential to heater means 124 through the series path provided by contact 140 which partially shunts resistor 134. It will be noted that relay 137 while deenergized maintains contact 139 in a closed position so that it completes a shunting path around substantially the greater part of both resistors 134 and 135 with relay 138 energized. Relay 138 will be energized only during that portion of the operating cycle when cam 152 is in contact with the left-hand side of lever arm 150. However, due to the dash pot arrangement 158, the contact 140 will remain in its closed position for longer than the period of energization of relay 138 and longer by a time dependent upon adjustment of valve 160.

Upon a corresponding increase in frequency in power lines 18 and 19 resulting from a sudden decrease in load on the tie-line system, the reverse cycle of operation is obtained from mechanical relay means 147. Under such a reverse cycle of operation, relay 137 is arranged to be energized, but since contact 139 is of the normally closed type, this contact will tend to open. When both

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contacts 139 and 140 are open the potential applied to heater 124 is reduced due to the increased resistance at 134 and 135 connected in series with said heater. By the operation of relays 137 and 138 it will be understood therefore that a further modification in the pressure in chamber 125 may be effected by increasing magnitude with increasing deviation from the control point or the selected value of frequency of 60 cycles per second, and independently of the change in control pressure due to change in the load connected directly to electrical generator output lines 16 and 17 which include wattmeter 120. In operation it has been noted that this further modifying action accomplished by relays 137 and 138 permits changes to be made in the air-loading pressure in line 28 considerably ahead of the time that a change in load is actually indicated by wattmeter 120. In this way a further anticipating action may be obtained for controlling the combustion rate of the energy-supplying means, such as boiler 10 of Fig. 1.

In addition to the anticipating action provided by frequency responsive bridge 141, in modifying the air-loading pressure in line 28, that bridge is also part of the control for varying the opening of the main control valve 12 in supply line 11 for turbine 13, as by changing the bias on spring 104 of the fly-ball governor 100. This action is accomplished by motor 170 which is arranged to be intermittently energized under the control of one or the other of the circuits completed by way of cams 151 and 152 of mechanical relay 147 to move nut 109. The length of time that each cam is in contact with lever 150, as before, is dependent upon the amount of unbalance which determines the degree of deflection of the lever 150. By the intermittent contacting of cams 151 and 152 with lever 150, a stepping operation is obtained from motor 170, the length of each step being dependent upon the degree of deflection of lever 150.

It will now be assumed that the frequency of the alternating current flowing through lines 18 and 19 departs from the desired value for a substantial period of time. Upon occurrence of said departure of frequency from the desired value, the frequency bridge 141 applies an unbalance signal to the galvanometer 146 of magnitude related to the extent of the departure from the predetermined value. The control impulses produced by the cam-contact mechanism are of length related to the extent of said departure immediately to produce the stepping operation of motor 170 and they are also effective to energize one of the relays 137 and 138.

The impulses applied to heater 124 immediately initiate a change in the level of pressure in line 28 to change the firing rate of boiler 10 in a direction to correct for the steam-load requirements needed to return the frequency at lines 18 and 19 to its desired value. By adjusting the position of the contacts on the resistors 134 and 135 the extent of the change in current in heater 124 upon each operation of a relay may be controlled for any desired augmentation of the control effect due to change of current therein, it being remembered that the time each relay remains in its energized position is dependent not only upon the extent of departure of the frequency from its desired value, but also upon the setting of each dash-pot which regulates the time before return of each relay to its deenergized position.

The stepping operation of motor 170 changes

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the setting of governor 100 and produces a change in position of the valve 12, in a direction to change the output of turbine 13 and of electrical generator 14 in a direction to return the frequency to its predetermined value.

As soon as there is change in the output of the generator 14, the wattmeter 120 adjusts the contact of variable transformer 128 further to change the heating current in heater 124. The further change in the heating current further changes the pressure within chamber 125 in a direction to augment the change resulting from the electrical impulses produced by relays 137 and 138. As long as there is adjustment of valve 12 changing the output of generator 14, there will likewise be adjustment of the variable transformer 128 continuously to change the current flowing through the heater 124.

A change in the output of electrical generator 14 adequate to produce adjustment of variable transformer 128 may not at once occur following a frequency deviation on supply lines 18 and 19. However, the operation of one or the other of relays 137 and 138 immediately initiates a corrective action which is not dependent upon a change in the output of generator 14. When there is a change in the output of generator 14, a new setting of variable transformer 128 will be made and maintained as long as there is the changed output on electrical generator 14, notwithstanding disappearance of unbalance from the bridge 141.

One of the purposes of the present invention is to maintain substantially constant the steam pressure in line 11. If a pressure change should occur in line 11, the Bourdon tube 30 adjusts lever or element 34 in a direction to add a further compensatory control effect by further changing the air pressure in line 28. The present invention provides combined response to (1) actual generator output and to (2) any action occurring which will result in a change in that output. Thus the anticipatory control of the generation of steam will avoid time-lag, hunting of the control system and will provide a stabilized control of great advantage in maintaining the controlled variable, e. g., frequency, at the control point, e. g., at sixty cycles per second.

Referring now to a further embodiment of the invention, as illustrated in Fig. 3, there is shown a system similar to those illustrated in Figs. 1 and 2 and in which similar numbers are used to designate similar elements. The control system for governing the flow of current in heater means 124 to produce a change in pressure in chamber 125 and in line 126 to effect the operation of master control means 26 is indicated as being similar to that already described in connection with Fig. 1 except for the inclusion of a wattmeter as the generator load response means instead of the current transformer of Fig. 1. It will be understood that the control system for heater means 124 may be of the type illustrated and described in connection with Fig. 2. However, as particularly distinguished from the system described in connection with Fig. 2, there is shown in Fig. 3 apparatus for modifying operation of the energy-converting means, the turbine 13 and generator 14, in response to a change in load conditions on the electrical power system to which the output lines 16 and 17 of generator 14 are interconnected. To this end a load responsive means, illustrated as a wattmeter 175 is connected across tie-lines 18 and 19 on the system side of the local load, indicated generally as 176,

which is directly connected to lines 16 and 17. Wattmeter 175 is arranged to position a movable contact 177 of a Wheatstone bridge arrangement 178. The contact 177 of bridge 178 is connected to one side of galvanometer coil 145a of mechanical relay means 147 while the opposite side of coil 145a is connected to the corresponding junction point or contact 179 on the opposite side of bridge 178. For the sake of simplicity in the drawing, mechanical relay 147 is indicated as controlling only motor 170 which is adapted to adjust the bias spring 104 of fly-ball governor 100 for controlling valve 12 on the inlet side of turbine 13. However, it will be apparent that as described in connection with Fig. 2, mechanical relay means 147 may perform the same operations with respect to heater means 124 as previously described. For the sake of illustration but not by way of limitation, the tie-line system is schematically represented by the distant load, indicated generally as 180, and by a further turbine-generator combination such as turbine 181 and electrical generator 182. These units are obviously only indicative of the complex combinations of power loads and energy-converting means normally interconnected in a tie-line power system.

It will be apparent that the operation of the system shown in Fig. 3 will be substantially similar to that shown in Fig. 2 with the exception that provision is made in the present embodiment for initiating and effecting the previously described control actions in response to a current, or voltage, change in the tie-line load as distinguished from a change in frequency, as shown and described in connection with Fig. 2.

In the systems of Figs. 1, 2 and 3 a change in demand on the steam generator 10 arises whenever there is change in pressure in line 11 caused by a change in load on turbine 13 and generator 14. The master control means 26 through the Bourdon tube 30 varies in a compensatory manner the rate of generation of the vapor or steam by the steam generator 10 as by adjustment of the fuel-feeding means 21 and the damper 24. In Fig. 1 the means for modifying the operation of the master control means 26 anticipates demand changes on the vapor or steam generator 10. Specifically, by providing the load responsive means 120, as a current transformer or an ammeter, for controlling the energization of the heater 124 there is produced a control quantity, the change in pressure in chamber 125, acting in compensatory direction and of magnitude to produce a regulating action to an extent related to the magnitude of the change in the electrical load condition of the generator 14. It will be seen the change in the rate of generation of the vapor or steam is in part made dependent upon change in load of the electrical generator, an event which occurs earlier than the change in load on the prime mover 13. It occurs earlier from the standpoint of the control system for the reason that a change in load on the generator must result in a change in speed of the generator which must be sensed by the governor 100 and must result in adjustment of throttling valve 12 before there is a change in pressure in line 11 due solely to the change in load on the electrical generator 14.

In the modification of Figs. 1-3 a change in the load of the electrical energy-converting means, such as generator 14, produces a continuing modifying action upon the master control 26 of substantial duration. With particular reference

to Fig. 2, the electrical impulses of variable length and of uniform amplitude not only control the energization of the heater 124, but they also control the setting of the governor 100. However, both with respect to the control of heater 124 by the potential-varying transformer 128 and by the relays 137 and 138, the heater 124 is energized for time intervals of substantially greater duration than the length of each of the control impulses. If reliance were solely made upon the impulses for varying the setting of the governor 100, modification of the control action would be of a different character than is achieved by the modifying action introduced by the heater 124 due to the energization thereof for periods greater than the control impulses. Thus, the modifying action due to heater 124 continues over a period of time adequate to result in a readjustment of the rate of vapor or steam generation adequate to compensate for the new load demand or demand of vapor from the generator 10, after which a new pressure has been established in chamber 45 and a new position has been fixed for rheostat 50 and damper 24 for continued operation of the generator 10 at a new rate which meets the new demand.

In the system as illustrated in Fig. 3 the continuance of the modifying action during the needed period of readjustment of the rate of generation of the steam is provided only by the load-responsive means 120 and without augmentation by the operation of the relays 137 and 138, though there is retained in Fig. 3 use of the control impulses for changing the setting of the governor 100.

While there has been illustrated the mechanical relay device 147 for producing the control impulses of uniform amplitude and of variable duration, it is to be understood that the same kind of control action will be achieved by providing impulses which may be of uniform amplitude but of variable frequency, the frequency being determined by the deviation of the controlled variable from its desired value. Those skilled in the art are familiar with devices and systems which produce impulses of frequency dependent upon the extent of departure of the controlled variable from the control point.

Reference is now made to Fig. 4 wherein there is illustrated an alternative arrangement to that shown in Fig. 2 and wherein provision has been made for eliminating the control of mechanical relay means 147 in response to variations detected by load condition responsive means 141, or 175. As particularly illustrated in Fig. 4, a double pole double throw switch 135 is provided in lines 153 and 154. With the two poles of switch 135 thrown to the righthand position as shown in Fig. 4, the mechanical relay means 147 is disconnected from relays 137 and 138 as well as from governor-adjusting motor 170. However, relays 137 and 138 as well as motor 170 may be operated manually by depression of either push button 186 or 187 to connect lines 153 and 154, respectively, to one side of battery 155. The opposite side of battery 155 is of course connected to the other side of the relay coils through line 161 as indicated in the embodiment shown in Fig. 2.

By the arrangement shown in Fig. 4 and thus far described, the operation of heater means 124 is under manual control to vary the pressure in chamber 125 and line 126 to effect thereby operation of master controller 26. Simultaneously, the operating conditions of fly-ball governor 100 are changed to vary the operating action of supply

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valve 12 for turbine 13. This manual control is desirable to effect manual load changes on electrical generator 14 which are in turn reflected back to the boiler or vapor generator supplying turbine 13.

One advantage in providing the manually operable means, as by the push buttons 186 or 187 operating to control the energization of the heater 124 either with or without concurrent control of the setting of governor 100, resides in the fact that when it is known that there is to be a change on the load of the electrical generator 14 and its prime mover 13, an operator may, by operating one or the other push buttons, immediately change not only the load to a new selected value but also and concurrently may immediately change the rate of generation of vapor or steam, thus to regulate the energy-supplying means, the boiler 10, to meet the new demands to be placed upon it. This is a decided advantage over arrangements in which there is only provided manual change in the setting of the governor, or other similar control devices, which only indirectly regulate the rate of steam generation.

There is illustrated in Fig. 5 a further modification in which the operation of a master controller means may be varied by a control quantity, such as pressure, applied at a point which directly varies the reset action. As shown in Fig. 5, chamber 125 containing heater means 124 may be connected to a bellows, or expansible chamber, 191 which is operably connected through a push rod 192 to a pivotal connection, such as pin 193, mounted directly on lever arm 34 of master control means 26. A bleed valve 194 is preferably provided for the interconnected space comprising chamber 125, bellows 191 and line 190 so that under steady-state conditions any differential of pressure in bellows 191 will disappear. It will be readily apparent to those skilled in the art that the operation of bellows member 191 and push rod 192 as applied to the force-balance system directly through pivot 193 and lever 34 produces a control action like that due to the introduction of a modifying pressure from chamber 125 into chamber 46 above the mercury column of controller 26.

Reference is now made to Fig. 6 wherein there is illustrated a further form of the invention. As particularly distinguished from the foregoing embodiments, wherein the pressure in chamber 125 is varied in response to changes in load conditions either on the electrical generator directly or on both the electrical generator and the tie-line system by heater means 124, in the present embodiment provision is made for varying the pressure in chamber 125 by a bellows 200. The pressure in bellows 200 and hence in chamber 125 is varied in response to changes in the electric load on the generator output lines 16 and 17. These variations in pressure are developed in response to changes in current detected by the secondary winding of a current transformer 201 adapted to measure the flow of current in line 16. The output of the secondary winding of transformer 201 is connected in series with a pair of solenoids 202 and 203 which are arranged in a force-balance system in which solenoid 203 is positioned on a slidable stationary support while opposing solenoid 202 is preferably mounted upon a support member 204, slidably mounted on a lever arm 205. Lever arm 205 is pivotally supported by a pivot member 206. Opposing the combined action of solenoids 202 and 203, there is provided a bellows 207 having a stationary

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support and adapted to actuate a push rod 208 which is pivotally connected to the opposite side of lever 205 by pin 209. Provision is made for utilizing the force-balance system represented by lever 205 by connection of a pilot, or throttling valve, designated generally as 210, which has an operating rod 211 pivotally connected to the end of lever 205 by pin 212. Operating rod 211 is arranged to move a pair of ball-valve members fixedly mounted thereon to form a pilot valve stem to admit or release compressed air through pipe 213 which may be supplied by the same source as that which provides loading-air pressure for control means 26. Compressed air supplied through line 213 is throttled by valve 210 into chamber 214, which through line 215 connects with the inner compartment of bellows 200 and through valve 216 with the inner compartment of bellows 207.

By virtue of the arrangement just described, an increase in current flowing in line 16 will increase the current flow in the secondary winding of transformer 201 to cause a greater attraction between solenoid coils 202 and 203 and thereby tend to rotate lever 205 in a counterclockwise direction, as viewed in Fig. 6. Such counterclockwise motion will operate rod 211 of valve 210 downwardly further to restrict the connection between chamber 214 and atmosphere and simultaneously further to open the valve in the connection to line 213, until the increased air pressure acting on bellows 207 balances the increased force at solenoid coils 202 and 203. When the air pressure in chamber 214 is thus increased, bellows 200 within chamber 125 is caused to expand, thereby increasing the pressure in both chamber 125 and line 126, and operating master controller 26 in a manner described hereinabove to increase the air-loading pressure in line 28. A corresponding decrease in current in line 16 will cause a corresponding decrease in the secondary winding of current transformer 201 and cause a reduction in the attractive force between solenoids 202 and 203 permitting pressure in bellows chamber 207 to rotate lever 205 in a clockwise direction, as seen in Fig. 6, and thereby further restrict the admission of compressed air through line 213 to chamber 214. Such action reduces air pressure in chamber 214, line 215, bellows 207, and bellows 200, thereby reducing the pressure in chamber 125 and causing a consequent reduction in loading pressure applied to line 28 by master control means 26.

An adjustable valve 216 may be employed which by the restriction provided thereby will introduce a response to rate of electric load change by restricting the rate of air pressure change within bellows 207. Such a rate action may be desirable to obtain an augmented control effect of the master control means 26 upon occurrence of rapid changes in electrical load.

A further modification in the operation of solenoids 202 and 203 in response to changes of load conditions on an interconnected tie-line is provided by the operation of mechanical relay means 147. However, as distinguished from the circuit shown in Fig. 2, provision is made for connecting a pair of resistance circuits in parallel with series-connected solenoids 202 and 203. As shown, one of these parallel branches is provided by resistor 217 which has in series therewith a contact 218 operable by a time-closing relay 219 while the other, parallel resistance branch is provided by resistor 220 having in series therewith contact 222 operable by a time-opening relay 221. The

dash-pots on the relays are similar to those described for relays 137 and 138 of Fig. 2. The operating coils of relays 219 and 221 are connected to a potential source, such as battery 155, through lines 153 and 154, in the same manner described in regard to Fig. 2. However, due to the fact that the resistors 217 and 220 are connected in parallel rather than in series as shown in Fig. 2, upon closing of normally-open contact 222 of relay 221 a decrease in current flow through solenoids 202 and 203 will be obtained, which as mentioned above will reduce the pressure in bellows 200 and chamber 125. Conversely, by opening normally-closed contact 218 of relay 219, the current flow through solenoids 202 and 203 will be increased thereby increasing the pressure in bellows 200 and chamber 125.

Operation of the embodiment shown in Fig. 6 may be further varied by virtue of the arrangement for slidably moving solenoids 202 and 203 along lever arm 205. By so moving the solenoids, adjustment of the control action is obtained. Thus characteristics of the control system may be readily varied to meet changing requirements of the system under control to provide close regulation without hunting or oscillation of the controlled variable, the frequency, about its selected value.

It will be apparent from the foregoing detailed description of numerous modifications that further modifications and changes may be made in the apparatus and methods described herein within the scope of appended claims. For example, it will be readily apparent that the control system is equally applicable to control systems operating entirely in response to an electrical potential as distinguished from an air-loading pressure provided by a pneumatic system such as that provided by air-loading pressure line 28. Likewise it will be apparent that any number of boilers or vapor generators operating a single energy-converting unit such as a turbine and electrical generator combination, or any number of turbines or electrical generators operated from a single vapor generator may utilize systems of the type disclosed in this specification.

For steady-state operation it is desirable to provide a relatively wide proportional band for the master controller 26, that is, to require a fairly wide range of pressure change on Bourdon tube 30 to operate the combustion control devices 21 and 24 from one limit to the other. If a narrow proportional band were utilized to make greater the change of setting of the devices 21 and 24, upon occurrence of a given change in pressure in tube 30 for a given load change, there would arise the likelihood of hunting or oscillation of the control system in an effort to establish generation of steam at the needed rate. By providing the modifying action by the control means including the relays 137 and 138 and by the other control means including the variable transformer 128, the combustion control devices 21 and 24 may be operated between their respective limits in the absence of any pressure change on the Bourdon tube 30, yet there is not introduced into the system any effects which tend to produce hunting or oscillation for the reason that change in the settings of the combustion control devices terminates upon return of the generator 14 to a steady-state condition of operation and upon return of the frequency of supply lines 18 and 19 to its selected value of sixty cycles per second.

What is claimed is:

1. A system of controlling a vapor generator connected to a prime mover driving an electrical generator comprising: a master control means, said master control means having an element responsive to change in demand upon the vapor generator for varying in a compensatory direction the rate of generation of vapor by the vapor generator, said master control means including an element responsive to the duration and extent of change in pressure of said vapor for modifying the action of said vapor generator in a direction to maintain substantially constant the pressure of said vapor under all vapor-demand conditions imposed upon it, and means for modifying the operation of said master control means to anticipate demand changes on the vapor generator comprising means responsive to the electrical output of the electrical generator, a quantity-producing means operable under the control of said last-named means for applying to said master control means a control quantity which, during periods of change in the electrical output of said generator acts upon said vapor generator to change its rate of vapor generation in compensatory direction and to an extent related to the magnitude of the change in a condition of the load supplied by the electrical generator, and which control quantity is without continued effect upon the magnitude of the vapor pressure which said master control means operates to maintain.

2. The combination set forth in claim 1 in which two controls are provided for said quantity-producing means, one control means being continuously responsive to change in the electrical output of the electrical generator, and the other control means being responsive to change of an electrical condition of the load supplied by the generator to initiate a modifying operation of said master control means in anticipation of a change in electrical generator output.

3. The combination set forth in claim 2 in which there is provided manual means for varying in a selected direction the magnitude of the control quantity applied by said quantity-producing means to said master control means independently of the load condition on the electrical generator.

4. The combination set forth in claim 3 in which the prime mover is provided with a governor, and in which governor-adjusting means is provided under the control of said manually operable means.

5. The combination set forth in claim 2 in which said second control means includes time-delay relays to change the control quantity produced thereby over time intervals greater than the duration of said impulses.

6. The combination set forth in claim 5 in which one time-delay relay has a normally closed contact and another time-delay relay has a normally open contact for respectively adjusting said quantity-producing means to change in opposite directions the magnitude of said control quantity in dependence upon the direction of change in the condition of the load supplied by the electrical generator.

7. The combination set forth in claim 2 in which the means responsive to a change in a condition of the load supplied by the electrical generator is connected in a tie-line system for response to change in the load of a remote part

of the system prior to appearance at the electrical generator of said load change.

8. Means for modifying the operation of a master control means to anticipate demand changes on a vapor generator supplying a prime mover, said master control means including a balanceable element positioned by a plurality of opposing forces to control the generation of vapor by the vapor generator, means for producing one of said forces in accordance with the magnitude of the pressure of the vapor supplied to said prime mover, means for producing another of said forces in accordance with the extent and duration of the departure of said vapor pressure from a predetermined magnitude, and means for modifying said other of said forces comprising a device responsive to a change of output of said prime mover, and means operable under the control of said device for temporarily unbalancing said balanceable element in a compensatory direction and by an amount related to the magnitude of change of said output.

9. A system for controlling the rate at which vapor is produced by a vapor generator connected to a prime mover driving an electrical generator comprising a master control means responsive to change in demand upon the vapor generator for varying in a compensatory direction the rate of generation of vapor by the vapor generator, a first control means responsive to change in the electrical output of the electrical generator for modifying the operation of said master control for producing compensatory change in the rate of generation of vapor, and a second control means operable to change the output of said electrical generator and for modifying the operation of said master control means to anticipate demand change on the vapor generator occasioned by the operation of said second control means to change the load on the electrical generator.

10. A system of controlling the rate at which energy is produced by an energy-supply means connected to an energy-consuming means driving an energy-converting means comprising a master control means, said master control means having an element responsive to change in demand upon the energy-supply means for varying in a compensatory direction the rate of generation of energy by the energy-supply means, said master control means including an element responsive to the duration and extent of change in potential of said energy for modifying the action of said energy-supply means in a direction to maintain substantially constant the potential of said energy under all energy-demand conditions imposed upon it, means for modifying the operation of said master control means to anticipate energy-demand changes on the energy-supply means comprising means responsive to change in the output of said energy-converting means, and means operable under the control of said means responsive to change of said output for applying to said master control means a control quantity which during periods of change in the output of said energy-converting means acts upon said energy supply means to change its rate of energy generation in compensatory direction and to an extent related to the magnitude of the change in said output of the energy-converting means and which control quantity is without continued effect upon the magnitude of the vapor pressure which said master control means operates to maintain.

11. A system of controlling the rate at which

vapor is produced by a vapor generator connected to a prime mover driving an electrical generator comprising a master control means including a control element movable by unbalance of a force-balance system which includes said element as a part thereof, means for moving said element in response to change in demand upon the vapor generator for varying in a compensatory direction the rate of generation of vapor by the vapor generator, reset means for moving said control element in response to the extent and duration of unbalance of said force-balance system, means for modifying the operation of said master control means to anticipate load demand changes on the vapor generator comprising means responsive to change in the output of the electrical generator, and means operable under the control of said last-named means for temporarily introducing an unbalanced force into said force-balance system by a control quantity which changes the balance of the force-balance system in compensatory direction and to an extent related to the magnitude of the change in said output of the electrical generator and which during periods of constant output of said electrical generator is without effect upon said force-balance system.

12. In a system of controlling the rate at which vapor is produced by a vapor generator connected to a prime mover driving an electrical generator comprising a master control means of the pneumatic type including a control element movable by unbalance of a force-balance system which includes said element as a part thereof, means for moving said element in response to change in demand upon the vapor generator for varying in a compensatory direction the rate of generation of vapor by the vapor generator, and reset means for moving said control element in response to the extent and duration of unbalance due to changes in vapor pressure, the combination of means for modifying the operation of said master control means to anticipate load demand changes on the vapor generator comprising means responsive to change in the output of the electrical generator, and means operable under the control of said last-named means for temporarily introducing an unbalance into said force-balance system by a pressure which changes the balance of the force-balance system in compensatory direction and to an extent related to the magnitude of the change in said output of the electrical generator and which during periods of constant output of said electrical generator is without unbalancing effect upon said force-balance system.

13. In a system of controlling the rate at which vapor is produced by a vapor generator connected to a prime mover driving an electrical generator comprising a master control means of the pneumatic type including a control element movable in response to change in demand upon the vapor generator by unbalance of a force-balance system which includes said element as a part thereof, means for moving said element for varying in a compensatory direction the rate of generation of vapor by the vapor generator, reset means for moving said control element in response to the extent and duration of unbalance of said force-balance system due to change in vapor pressure, the combination of means for modifying the operation of said master control means to anticipate load demand changes on the vapor generator comprising means responsive to change in the output of

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the electrical generator, pressure-varying means for introducing an unbalance into said force-balance system by a pressure which changes the balance of the force-balance system in compensatory direction and to an extent related to the magnitude of the change in said output of the electrical generator and which during periods of constant output of said electrical generator is without unbalancing effect upon said force-balance system.

14. In a system of controlling the rate at which vapor is produced by a vapor generator connected to a prime mover driving an electrical generator, the combination of a master control means of the pneumatic type and including as a part thereof a control element movable by unbalance of a force-balance system in response to change in demand upon the vapor generator for varying in a compensatory direction the rate of generation of vapor by the vapor generator, means for modifying the operation of said master control means to anticipate load demand changes on the vapor generator comprising means responsive to change in the output of the electrical generator, a heater disposed within a closed chamber and operable under the control of said last-named means for developing unbalance in said force-balance system by control of the magnitude of a pressure applied thereto which changes the balance of the force-balance system in compensatory direction and to an extent related to the magnitude of the change in said output of the electrical generator.

15. In a system for controlling the rate at which vapor is produced by a vapor generator connected to a prime mover driving an electrical generator, the combination of a master control means including as a part thereof a control element movable by unbalance of a force-balance system in response to change in demand upon the vapor generator for varying in a compensatory direction the rate of generation of vapor by the vapor generator, means for modifying the operation of said master control means to anticipate load demand changes on the vapor generator comprising means responsive to change in an electrical load condition of the electrical generator, control-quantity-producing means operable under the control of said last-named means for introducing unbalance into said force-balance system by said control-quantity which changes the balance of the force-balance system in compensatory direction to an extent related to the magnitude of the change in said electrical load condition of the electrical generator, and means responsive to a different electrical condition for controlling said quantity-producing means to augment the magnitude of the control-quantity produced by change in the electrical load condition of the electrical generator.

16. The combination set forth in claim 15 in which the output of the electrical generator and the frequency of the power system to which the electrical generator is connected are the respective conditions controlling the magnitude of the control-quantity produced by said quantity-producing means.

17. In a system for controlling the rate at which vapor is produced by a vapor generator connected to a prime mover driving an electrical generator forming a part of an interconnected power system, the combination of a master control means and including as a part thereof a control element movable by unbalance of a force-

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balance system in response to change in demand upon the vapor generator for varying in a compensatory direction the rate of generation of vapor by the vapor generator, means for modifying the operation of said master control means to anticipate load demand changes on the vapor generator comprising means responsive to change in a load condition of the power system supplied by the generator, means responsive to change from a predetermined value of the frequency of the power system, and control-quantity-producing means operable under the joint control of said load-responsive means and of said frequency-responsive means for introducing unbalance into said force-balance system by a control quantity which changes the balance of the force-balance system in compensatory direction and to an extent related to the magnitude of the change in said electrical load condition and of said deviation from a desired value of said frequency of the power system.

18. In a system comprising a steam generator, a prime mover operably connected to said steam generator, and an electrical generator driven by said prime mover, the output of said electrical generator being connected to a power supply system, a control system comprising a master control means responsive to variations in steam load on said steam generator for controlling the firing rate of said steam generator, means responsive to an electrical load condition imposed on said electrical generator for producing a control quantity variable in response to changes in said load condition, means for varying the operation of said master control means in accordance with said changes in said control quantity, and means responsive to changes in the electrical load on said power supply system for further modifying the operation of said control system to anticipate changes in the electrical load condition imposed on said electrical generator.

19. In an automatic system for controlling the flow of fuel and combustion air to a steam generator to maintain the flow of steam from the steam generator to a steam-consuming device at a predetermined pressure with varying load-demand, the combination of means for regulating rates of flow of fuel and of combustion air in accordance with rate of steam flow from said steam generator to said steam-consuming device, and non-linear responsive means operable in response to the output of said steam-consuming device for introducing into said regulating means unequal increments of control action to change by equal increments said flow of fuel and combustion air with equal incremental changes in said output, the inequality between said unequal increments increasing with increasing load on said steam-consuming device and decreasing with decreasing load.

20. In an energy-conversion system for controlling the generation of energy to maintain the flow thereof to an energy-converting device at a predetermined potential under conditions of varying load-demand, the combination of means for regulating the rate of generation of said energy substantially in accordance with a root of the change in potential of said energy flowing to said energy-converting device and in a direction to return said potential toward a predetermined value, and non-linear responsive means operable in response to the output of said energy-converting device for introducing into said regulating means unequal increments of control action to change by equal increments the rate of genera-

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tion of energy for equal changes in said output, the inequality between said unequal increments increasing with increasing output of said energy-converting device and decreasing with decreasing output.

21. A system of controlling the rate at which vapor is produced by a vapor generator connected to a prime mover driving an electrical generator comprising a master control means responsive to change in demand upon the vapor generator for varying in a compensatory direction the rate of vapor produced by the vapor generator, means for modifying the operation of said master control means to anticipate demand changes on the vapor generator comprising solenoid means responsive to change in a condition of the load supplied by the electrical generator for producing a control force in a force-balance system, and means operable upon change in the magnitude of said force for applying to said master control means a force modifying its operation in compensatory direction and to an extent related to the magnitude of the change in said electrical load condition of the electrical generator.

22. The combination set forth in claim 21 in which said solenoid means are adjustably supported in said force-balance system for varying the magnitude of the force applied to said master control for a given magnitude of the force developed by said solenoid means.

23. A system for controlling the rate at which vapor is produced by a vapor generator connected to a prime mover driving an electrical generator comprising a master control means responsive to change in demand upon the vapor generator for varying in a compensatory direction the rate of

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fuel combustion in said vapor generator, a first control means responsive to change in the electrical output of the electrical generator for modifying the operation of said master control means, a second control means operable to change the output of said electrical generator and for further modifying the operation of said master control means, the modifying action upon said master control means by said first control means and by said second control means effecting materially greater changes in the rate of combustion of fuel in the vapor generator than would be accomplished by the master control means if operated solely in response to a change in demand upon said vapor generator and in the absence of said modifying action.

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