

- [54] SYSTEM AND METHOD FOR TRANSFERRING BETWEEN BOILER-TURBINE PLANT CONTROL MODES
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- [51] Int. Cl.² F01D 17/02; G05B 15/02
- [58] Field of Search 235/151.21; 60/646; 290/40 R, 40 A-C, 40 F; 340/172.5; 415/17; 444/1

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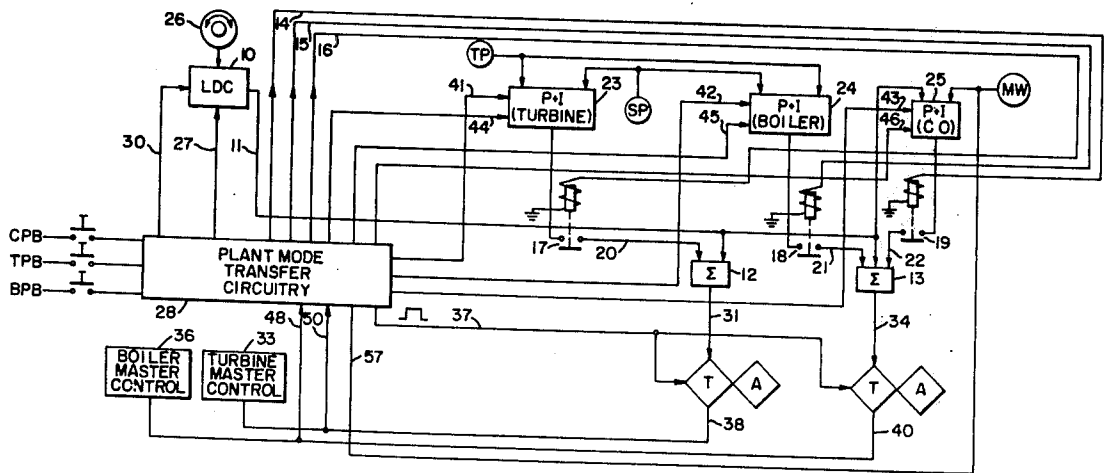
[57] **ABSTRACT**

A boiler-steam turbine plant control system for trans-

ferring between boiler-follow, turbine-follow, and coordinated operating modes, without any change in the output of the turbine or the firing rate of the boiler, is disclosed. A feedforward load demand signal controls both the turbine and boiler in parallel. In the turbine-follow mode, a feedback loop trims the feedforward signal to the turbine only. In the boiler-follow mode, a feedback loop trims the feedforward signal to the boiler only. In the coordinated mode, feedback loops trim the feedforward signal to both the turbine and boiler. In response to initiating a transfer to either the boiler or turbine-follow mode, the load demand signals which are controlling the boiler and turbine are held at their pre-transfer value; and the feedforward signal is modified to equal the pre-transfer value of the trimmed feedforward signal. A signal, which is equal in value to the pre-transfer value of the feedforward signal less the value of the trimmed feedforward signal is generated in the output of the feedback loop which is to be placed in service as a result of the transfer.

To transfer to the coordinated mode, the feedforward signal is modified to equal a signal representative of the actual power output of the plant. The turbine feedback loop generates a signal representative of the pre-transfer turbine demand signal less the modified feedforward signal. The boiler feedback loop generates a signal representative of the pre-transfer boiler demand signal less the modified feedforward signal.

15 Claims, 9 Drawing Figures



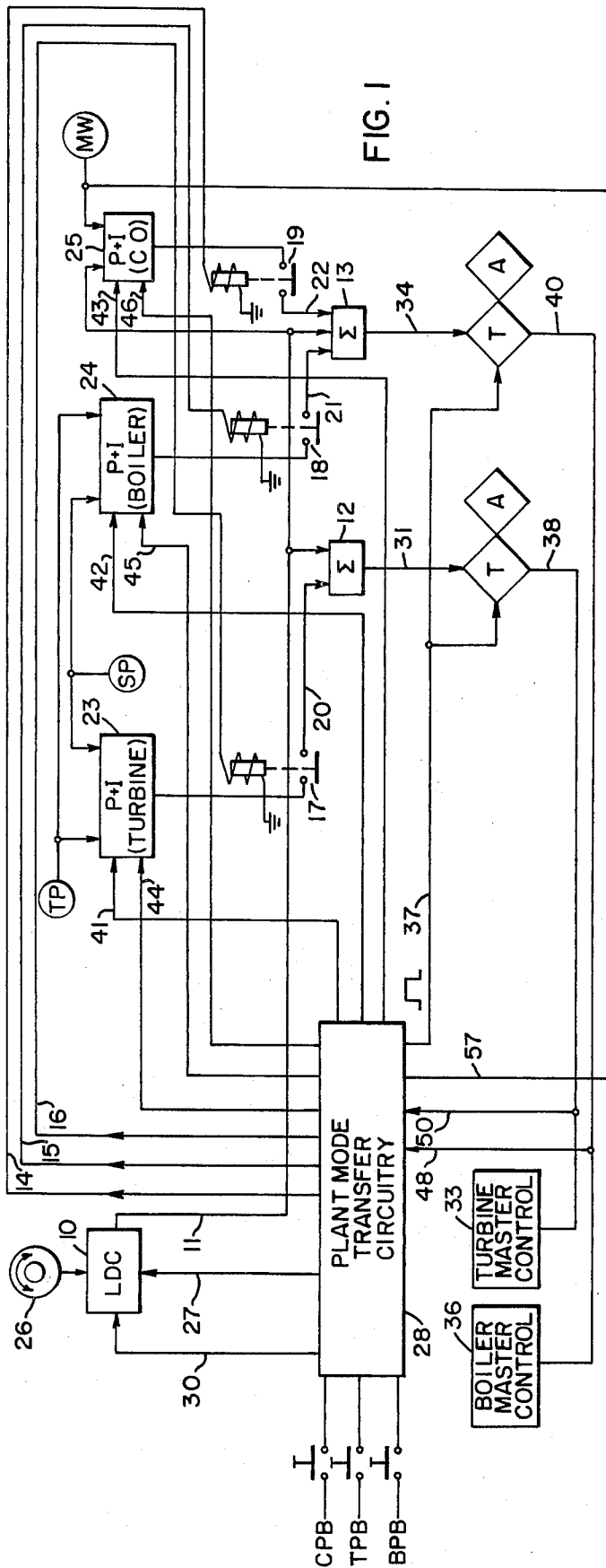


FIG. 1

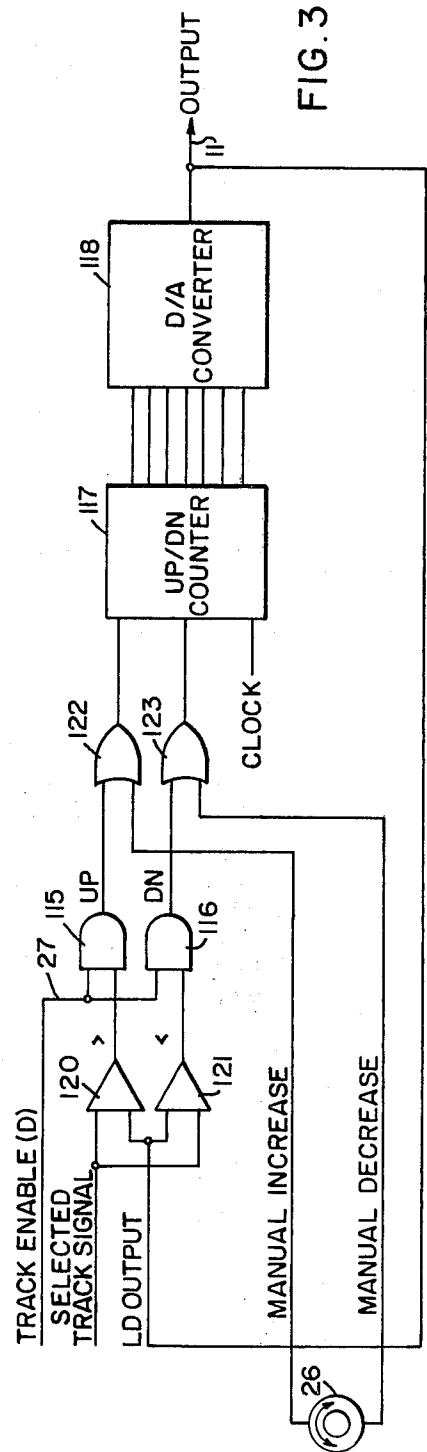


FIG. 3

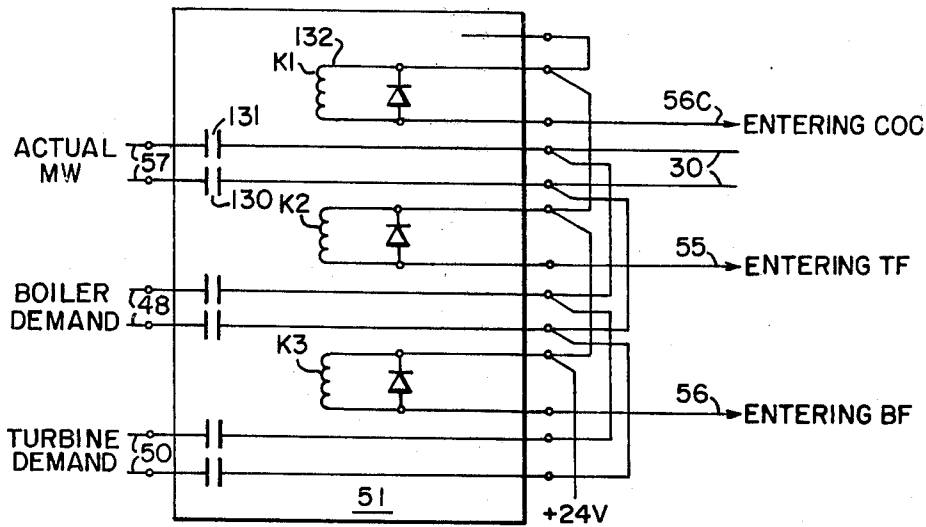


FIG. 4

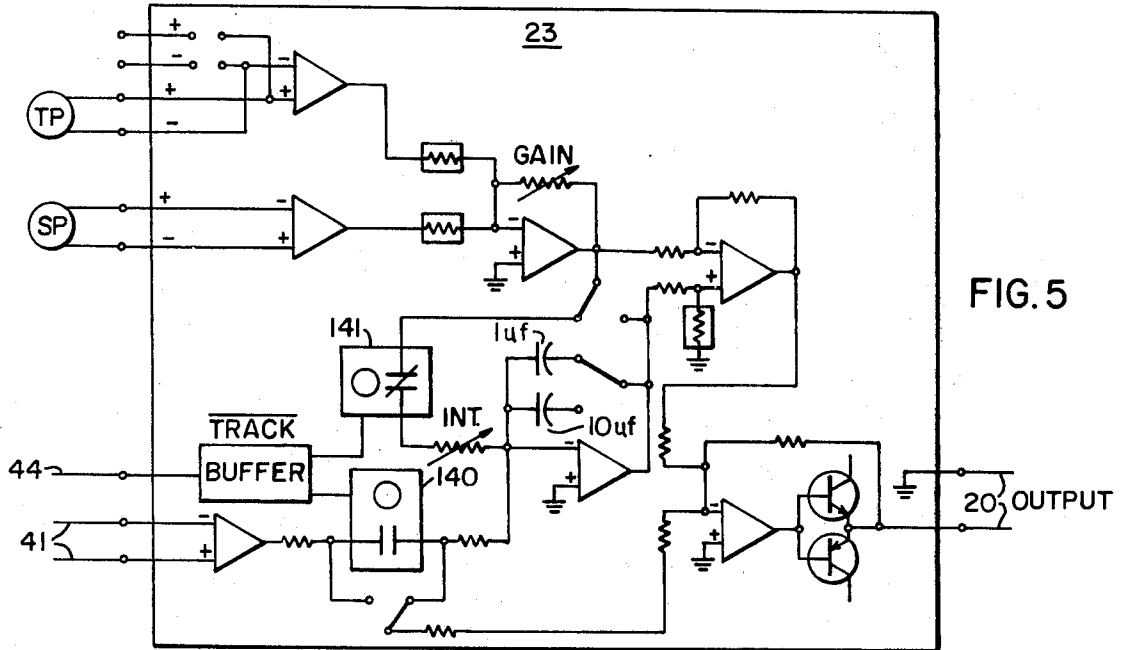


FIG. 5

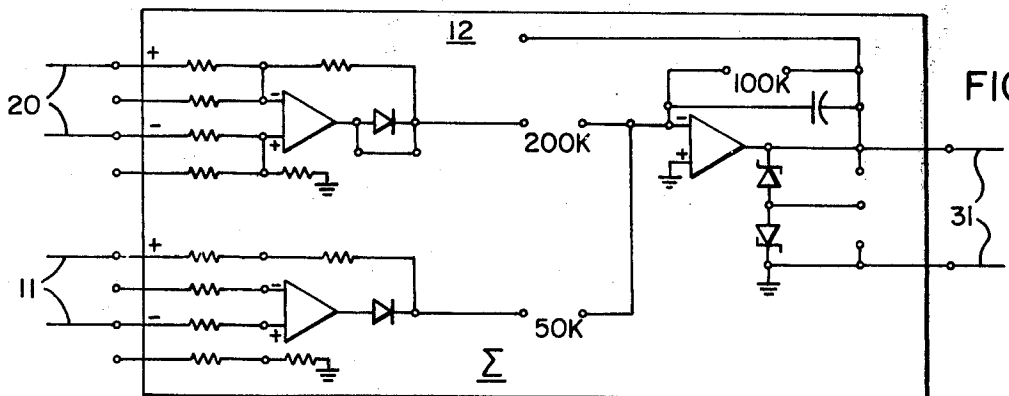
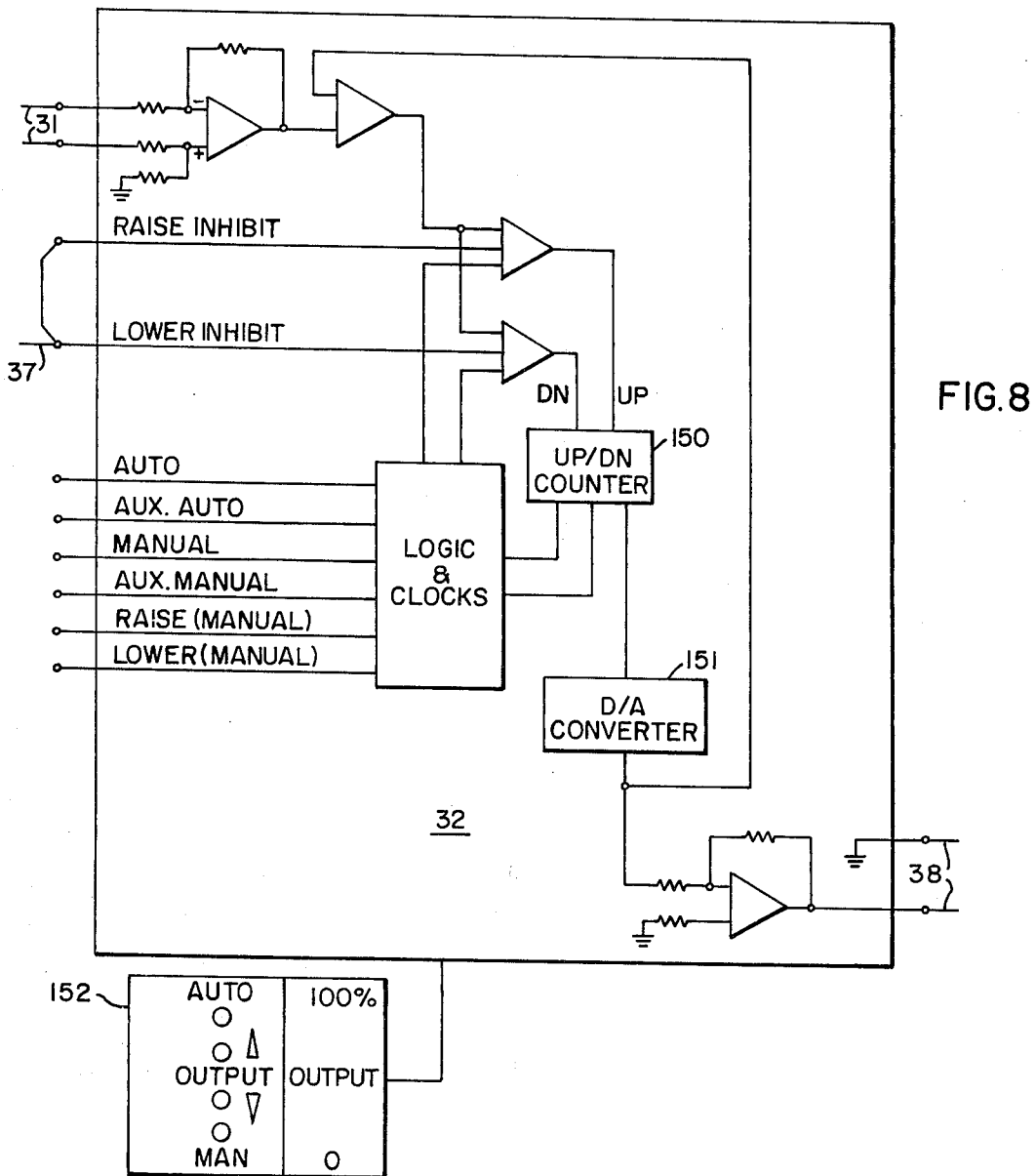
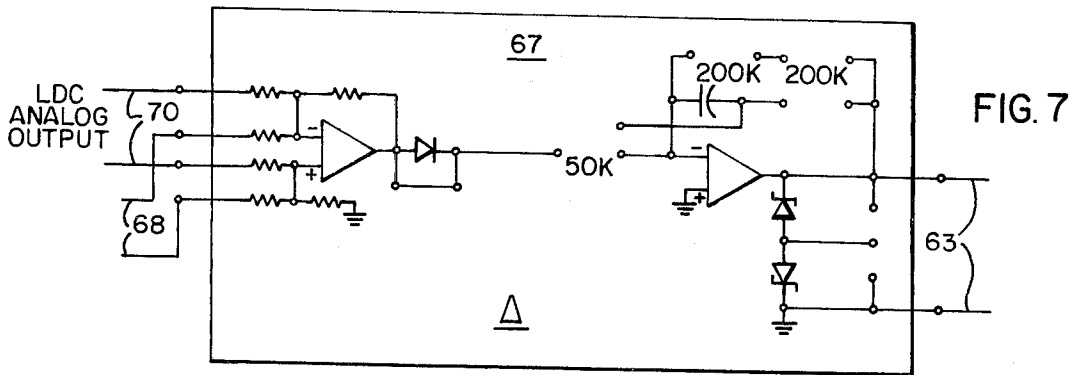


FIG. 6



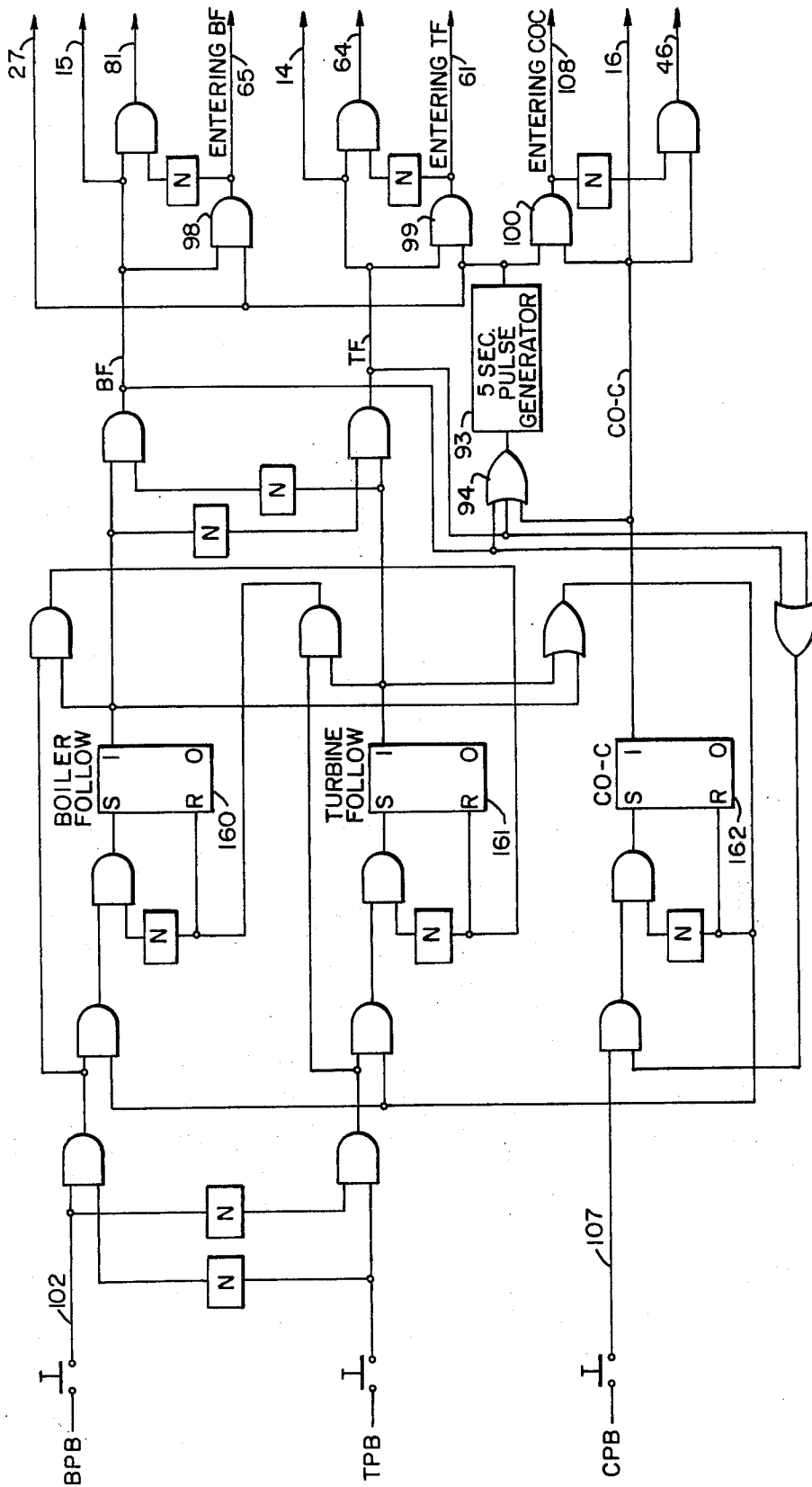


FIG. 9

SYSTEM AND METHOD FOR TRANSFERRING BETWEEN BOILER-TURBINE PLANT CONTROL MODES

CROSS-REFERENCE TO RELATED APPLICATIONS

U.S. patent application Ser. No. 413,291 entitled "Plant Unit Master Control For Fossil Fired Boiler, Implemented With A Digital Computer" filed by Guy E. Davis and Jack R. Smith on Nov. 6, 1973, and assigned to a common assignee is hereby incorporated by reference.

BACKGROUND OF THE INVENTION

The present invention relates to control systems for power plants; and more particularly to a system for transferring rapidly between operating modes without a change in the output of the turbine or the firing rate of the boiler.

The improved control of power generation is accomplished efficiently by achieving a close coordination of the boiler and turbine controls. This control is achieved by a plant master control unit or load demand computer, which generates a feedforward load demand signal that is connected in parallel to a turbine master control apparatus for operating the steam inlet valves to a predetermined position in accordance with the valve of the feedforward signal, and to a boiler master control apparatus for controlling the fuel, air, and water to the boiler at a predetermined rate in accordance with the value of the feedforward signal. The feedforward demand signal from the load demand computer minimizes interaction between the turbine and boiler, and extracts the best possible dynamic response of the plant.

In addition, under normal steady-state operating conditions, the load demand signal to the turbine and the boiler master control is trimmed by an error signal from an analog feedback loop, in response to detection of throttle pressure error and megawatt pressure error. In particular, the measured throttle pressure is compared to a reference level determined by a set point to provide the throttle pressure error signal, which is integrated and applied to the turbine control. The output of the turbine is measured and compared with a reference to provide megawatt error, which is integrated and applied to the boiler control.

A typical modern plant control system provides for several different modes of operation for various plant conditions. For example, in the above described mode, which may be termed a coordinated mode, a throttle pressure error feedback loop and a megawatt error feedback loop is in service. One feedback loop trims the load demand signal to the boiler control with the megawatt error signal; and the other feedback loop trims the turbine load demand signal to the turbine control with the throttle pressure error signal. In this mode, an increasing load demand results in the throttle pressure and megawatt generation to be low. Thus, the throttle pressure set point is increased by an amount proportional to generator error; and at the same time the firing rate of the boiler is increased, the throttle pressure is lowered momentarily as the governor valves are opened to permit greater steam flow.

In the event of certain abnormal conditions, the system can be transferred either automatically or manually to either a boiler-follow or a turbine-follow mode.

If an unusual turbine condition develops, the system is transferred to the boiler-follow mode wherein the feedforward signal from the plant unit master or load demand computer determines the load demand at a predetermined constant value; and as a result, the governor valves of the turbine are set to a position corresponding to such load demand signal. The input signal to the boiler continues to be trimmed by the analog feedback loop in order to obtain the desired throttle pressure. If an unusual boiler condition develops, the system is transferred to the turbine-follow mode wherein the feedforward signal sets the boiler to operate according to predetermined limits, and the feedforward signal is trimmed by the turbine feedback loop to adjust the governor valves to maintain a substantially constant pressure.

In the event that there is no error signal on the feedback loop in service at the time of the transfer, the megawatt output of the plant, of course is not affected by such transfer. However, such a situation is not ordinarily the case. Usually, the plant is operating with a positive or negative error on the output of the feedback loop. Although variations in the BTU capacity of fuel oil in a boiler creates such a condition, the problem is aggravated in plants where coal is used, to the extent that the feedback error signal can vary up to fifteen percent of the feedforward load demand from one grade of coal to another, thus, when one of the feedback loops is taken out of service, the error signal is removed, which in turn, causes the megawatt output of the generator firing rate of the boiler, or position of the turbine valves to change abruptly. Of course, any change occasioned by such transfer is undesirable; and an abrupt change is particularly undesirable.

Heretofore, a transfer between operating modes such as from the turbine-follow mode, to the boiler-follow mode, for example, was effected without an abrupt change in the output of the turbine by gradually eliminating, or in other words decaying, the error signal from the feedback controller in the analog loop of the turbine to zero. The throttle pressure error feedback loop is connected to the boiler control at zero error; and when the output of the turbine feedback loop is decayed to zero, it is taken out of service to complete the transfer. Thus, the system is then operating in the boiler-follow mode with the load demand signal to the turbine being uncorrected while any pressure deviations are trimmed by the throttle pressure feedback loop to the boiler.

Although, the above method and system eliminated the undesirable abrupt change in the position of the turbine inlet valves and the firing rate of the boiler, it did not eliminate a change in the megawatt output of the turbine, and the time required to effect such a transfer, depending on the mode to which the transfer is made, could consume as such as 10 minutes, for example.

In view of the increasing power demands placed upon large generating systems, it becomes increasingly important to provide a reliable power output without a change, be it ever so gradual, even for a period in the neighborhood of ten minutes. The problem in such transfers is not only one of correcting for the feedback signal of the analog loop to be removed from service; but it is also a problem concerned with the effect on the system of the analog feedback loop being placed in service. Thus, it is desirable to be able to effect a transfer between the various operating modes, rapidly, such as

in the neighborhood of five seconds or less, for example, without any undesired change in the position of the steam inlet valves, boiler firing rate, or megawatt output of the plant, which would be occasioned by such transfer.

SUMMARY OF THE INVENTION

Broadly, the present invention relates to a system and method of transferring from one plant control mode to another in a boiler-steam turbine power plant wherein a feedforward signal representative of the desired plant load is generated to control in parallel the boiler portion of the plant and the steam turbine portion of the plant in each of the modes. The trimmed and untrimmed load control signals to both the boiler and the turbine are held at their pre-transfer value in response to the initiation of a transfer.

The feedforward signal is modified to represent a selected value depending on the operating mode being entered. If one of the control apparatus is to be operated with no feedback loop in service, the selected value is the pre-transfer value of its trimmed input.

For each of the loops to be put in service as a result of the transfer, a feedback signal is generated so that the input signal to its respective boiler and turbine control apparatus is representative of the boiler and turbine control apparatus input signal which is held at its pre-transfer value. Upon completion of the transfer, the boiler and master control are permitted to respond to their respective trimmed and untrimmed signals in the transferred mode.

In a specific aspect, the system includes a load demand computer which generates feedforward signals in parallel to the turbine and boiler control apparatus. A feedback loop is provided for the turbine control apparatus which trims the feedforward signal to correct for any deviation in throttle pressure. A feedback loop is provided for the boiler control apparatus to correct for any deviation in throttle pressure; and a feedback loop is provided for the boiler control apparatus which operates in conjunction with the feedback loop for the turbine control apparatus to correct for throttle pressure and megawatt error. Each one of the feedback loops includes a proportional plus integral controller, and its error signal is summed with the feedforward signal to provide the trimmed signal. A manual/automatic transfer device for each master control apparatus receives the signal from the summing device and generates a signal corresponding to the summed signal for its associated master control. In response to the initiation of a transfer, a digital pulse of predetermined duration is generated, which governs each manual/automatic station to hold its output signal at its pre-transfer value. The feedforward signal to each of the summing devices is modified to be representative of a selected pre-transfer value, which selected value for a transfer where a particular control apparatus will have no feedback loop in service is the pre-transfer value of the output of the manual/automatic station for such control apparatus. For the feedback loops to be placed in service, the feedback controller is governed to generate an output signal for input to each summing device representative of the pre-transfer value of the output of the manual/automatic transfer station less the modified feedforward signal to the summing device.

In transferring to the coordinated mode, for example, the feedforward signal is modified to be representative of the actual megawatt output of the plant. The turbine

or boiler feedback loops are each operated to generate a signal which is representative of the pre-transfer output of its manual/automatic station less the modified feedforward signal. The outputs of the feedback loops are summed with the modified feedforward signal.

In response to termination of the digital pulse, the hold on the output signal of both manual/automatic stations is released, and the feedback controller for the connected loop is permitted to change its signal to the summing device in accordance with the error between the actual pressure or megawatts and the set point as the case may be.

IN THE DRAWINGS

FIG. 1 is a schematic block diagram, which illustrates the plant mode transfer circuitry connected to the feedforward and feedback controls of a plant control system according to one embodiment of the invention;

FIG. 2 is a schematic block diagram of the circuitry in one embodiment of the present invention;

FIG. 3 is a schematic diagram of a typical load demand computer for use in the system of the invention;

FIG. 4 is a schematic diagram of one form of a signal selector for use in the system of the invention;

FIG. 5 is a schematic diagram of one form of a proportional plus integral feedback controller for use in the system of the invention;

FIG. 6 is a schematic diagram of one form of a summing device for use in the system of the invention;

FIG. 7 is a schematic diagram of one form of a difference function device for use in the system of the invention;

FIG. 8 is a schematic diagram of one form of a manual/automatic station for use in the system of the invention; and

FIG. 9 is a schematic diagram of one form of a mode select logic circuit for use in the system of the invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring specifically to FIG. 1, there is shown schematically a general block diagram of an analog plant control system wherein analog feedback error signals are selectively connected to be summed with a feedforward signal for operating the turbine and boiler control in accordance with a selected plant operating mode; and includes a block diagram of a system for transferring between such operating modes with a change in the position of the turbine inlet valves, boiler firing rate, or the megawatt output of the turbine.

A load demand computer 10, which is shown in detail in FIG. 3 generates a load demand signal on its output 11 to the input of summing devices 12 and 13, the details of which are shown in FIG. 6. The load demand computer 10, may be any signal generating device which functions as disclosed, and is constructed to generate a feedforward signal, the value of which is calculated to correspond to a desired load for the plant. A mode select pushbutton BPB is operated to place the plant in a boiler-follow mode; a mode select pushbutton TPB is operated to place the plant in a turbine-follow mode; and a pushbutton CPB is operated to place the plant in a coordinated mode. In response to the operation of selected ones of the pushbutton BPB, TPB, and CPB, logic circuitry described in connection with plant mode transfer circuitry 28 is employed to energize selected ones of the outputs 14, 15 and 16, for

opening or closing respective relay contacts 17, 18 and 19, to connect and disconnect outputs 20, 21 and 22 of feedback controllers 23, 24 and 25, for input to the associated summing devices 12 and 13. Although, conventional relays and contacts are shown for the sake of simplicity, it is understood that other type switching circuits may be used.

The load demand computer 10 may also include a device 26 for increasing or decreasing manually the value of the analog signal on its output 11. This, of course, in an actual plane may be also accomplished automatically. The load demand computer 10 also includes an input 27, which, when energized by a digital signal from the transfer circuitry 28, the details of which are shown in FIG. 2, functions to modify the feedforward signal on the output 11 to be equal to an analog signal on input 30 from the transfer circuitry 28; or in other words the load demand computer 10 tracks the value of the signal on the input 30, when the input 27 is energized.

The feedforward signal on the output 11 of the load demand computer 10 is connected in parallel to a turbine master control 33 and to a boiler master control 36. The signal to the summing device 12, is conducted by way of output line 31 to the manual/automatic station 32; for input to the turbine master control mechanism 33. The signal on the output 11, which is input to the summing device 13, is conducted by output 34 to a manual/automatic station 35 for input to the boiler master control 36.

It is understood that the analog summing devices 12 and 13 may be of the type shown in FIG. 6, or any well known device that functions as described herein. The manual/automatic stations 32 and 35 may be of the type shown in detail in FIG. 8, which function to either increase or decrease the value of an analog signal manually or automatically. Each of the manual/automatic stations 32 and 35 also function to prevent the manual/automatic stations 32 and 35, when in automatic, from responding to a change in the value of a signal on their input lines 31 and 34 at times when a digital signal is present on output 37 of the transfer circuitry 28. In other words, the presence of a signal on line 37 prevents a change in the value of the signal on line 38 to the turbine control mechanism 33, and on line 40 to the boiler control mechanism 36.

The turbine master control 33 may be of the type that is well known in the art, and includes all apparatus necessary to position the steam inlet valves to the required position in accordance with the value of the signal on its input 38. The boiler master control 36 also may be of any well-known type that functions to adjust the fuel air and feedwater of the boiler to control its firing rate in accordance with the value on the input signal 40.

The feedback controllers 23, 24 and 25 provide the output error signals for input to the summers 12 and 13 depending upon the particular control mode in which the system is operated. Each of the controllers, the details of which are shown in FIG. 8 for the preferred embodiment of the invention, is a proportional plus integral type controller which produces at its respective output 20, 21 an error signal, which trims the feedforward signal on output 11, for more accurately controlling the turbine and boiler master control mechanism 33 and 36. Associated with each of the controllers 23 and 24 is a device TP for detecting the actual throttle pressure of the plant during operation, and a set point input SP for applying to its controller the desired throttle pressure. The signal from TP is compared with the

set point signal from SP to determine the value of the error signal at the output of its associated controller 23 and 24. The feedback controller 25 detects the actual megawatt output from the turbine by a detector MW, which is compared with the feedforward signal on the output 11 of the load demand computer 10 to provide an error signal on output 22, which corresponds to the difference between the desired megawatt output and the actual megawatt output of the plant. The feedback controllers 23, 24 and 25 also include respective analog inputs 41, 42 and 43, and respective digital inputs 44, 45 and 46 from the plant load transfer circuitry 28. Each of the controllers function to generate at their respective outputs 20, 21 and 22, a signal representative of the analog signal on the associated inputs 41, 42 and 43 at times when a digital signal is present on the respective inputs 44, 45 or 46 from the plant load transfer circuitry 28. Thus, in response to a digital signal on lines 44, 45 and 46, which may be termed track enable inputs, the associated feedback controller conducts an analog signal on its respective output 20, 21, 22, which is representative of the value of the analog signal on its associated input 41, 42 and 43. This function may be referred to as the feedback controller tracking a particular analog signal; and the purpose of which is discussed in detail in connection with the description of FIG. 2.

When the plant is in the turbine-follow mode, the feedback controller 23 is connected to the summing device 12 through the closed contact 17, and the feedback controllers 24 and 25 are disconnected from the summing device 13 because of the open condition of the contacts 18 and 19. Thus, the feedforward signal on the output 11 of the load computer 10 governs the boiler master control without correction; while any difference between the actual throttle pressure and the throttle pressure set point is corrected by the error signal on the output 20 of the feedback controller 23, which is summed with the feedforward signal on the output 11 by the summing device 12. The output of the summing device 12 conducts the corrected or trimmed feedforward signal by way of output 31, to the manual/automatic station 32, which in turn applies such signal to the turbine master control 33 by way of its output 38. Therefore, in the event of an error between the actual throttle pressure and the desired throttle pressure as indicated by the detector TP and set point SP, the turbine inlet valves are opened or closed to a greater or lesser extent than commanded by the feedforward signal in order to maintain the throttle pressure at the desired set point.

In the boiler-follow mode, the feedback controller 24 is connected to the summing device 13 through closed contact 18, and the feedback controllers 23 and 25 are disconnected from the respective summing device 12 and 13 because of the open condition of the contacts 17 and 19. Thus, the feedforward signal on the output 11 controls the turbine valves without correction; and the firing rate of the boiler is increased or decreased to compensate for variations in the set point pressure, by the feedback signal on the output 21 which is summed with the feedforward signal by the summing device 13 to conduct a corrected or trimmed signal to the manual/automatic controller 35 for governing the boiler firing rate through the boiler master control mechanism 36.

In the coordinated mode, the feedback controllers 23 and 25 are connected to the summing devices 12 and

13 respectively through the closed contact 17 and 19; and the feedback controller 24 is disconnected from the summing device 13 because contact 18 is open. In this mode, the feedforward signal on output 11 of the load demand computer 10 is modified or trimmed by the throttle pressure error signal from the feedback controller 23 to adjust the turbine inlet valves; and also, the feedforward signal 11 to the summing device 13 is modified or trimmed by a megawatt error signal from the feedback controller 25 to adjust the firing rate of the boiler in accordance with any deviation in the desired megawatt output of the plant, as determined by the megawatt detector MW.

A transfer from one operating mode to another is initiated by the operation of the appropriate pushbutton BPB, TPB and CPB to govern the transfer circuitry 28 to hold the input signals to the turbine and boiler master controls 33 and 36 to the pre-transfer value to connect and disconnect the feedback controllers 23, 24 and 25, as previously discussed; and to change the output of the load demand computer 10 in accordance with analog input signals on lines 48 or 50 as the case may be; all as described, in detail in connection with FIG. 2, in order that a transfer is effected without disturbing the position of the turbine inlet valves, boiler firing or megawatt output of the plant.

Referring to FIG. 2, the plant mode transfer circuitry 28 is illustrated as being enclosed by the dashed lines. The portions of the circuitry of FIG. 2 which are common with the circuitry of FIG. 1 bear similar reference numerals. It is to be understood that, although certain of the components and circuitry are shown in the preferred embodiment as being part of the mode transfer circuitry 28, in actual practice, some or all components may be structured within the feedback controllers 23, 24 and 25, the load demand computer 10, the turbine master control 33, or boiler master control 36, for example.

The plant mode transfer circuitry 28 in the described embodiment includes similarly constructed tracking signal selectors 51, 52, 53 and 54, one form of which is shown in FIG. 4. However, each of the tracking signal selectors may be any well-known analog device which responds to a signal to conduct a selected analog signal at its output. For example, the signal selector 51 functions to conduct an analog signal on its input 50 over its output 30 in response to a digital signal on its input 55. Also, the presence of a signal on its input 36 operates the selector 51 to conduct the analog signal on its input 48 over its output 30; and the presence of a digital signal on its input 56C selects an analog signal on line 57 for input to the LDC 10 over output line 30. Thus, the signal on the output 11 of the load demand computer 10 is either increased or decreased in accordance with the value of the signal on line 30. The signal on the output 11 may be either increased or decreased manually by manipulation of the mechanism 26, or either increased or decreased by remote control apparatus of the plant referred to at block 58.

The tracking signal selector 52 functions to conduct an analog signal of zero value on its output 41 to the feedback controller 23, as represented by its input 62 in response to a digital signal on its input 60. The presence of a digital signal on input 61 causes the selector 52 to conduct on line 41 the analog signal on its input 63. At times when the input 44, which may be termed a track enable input, of the controller 23 is energized, the controller tracks, or in other words generates at its

output 21 an analog signal corresponding to the value of the signal on line 41. When the track enable input 44 to the controller 23 is deenergized, the output signal on line 21 corresponds to the difference between the actual throttle pressure and the set point throttle pressure as determined by the signal from the elements TP and SP. Similarly, in response to a digital signal on input 64 of the selector 53, a signal of zero potential is input to the controller 24 to generate a zero signal on its output 21 at times when track enable input 45 to the controller 24 is energized. In response to a digital signal on input 64 of the selector 53, the selector conducts an analog signal on its output 42, which in turn governs the controller 24 to track the value of the signal on input 66 of the selector 53 at times when the track enable input 45 is energized. At times when the input 45 of the controller 24 is deenergized, the controller generates at its output 21 a signal corresponding to the difference between the set point signal represented by element SP and the actual throttle pressure detected by TP. Also, the signal selector 54 functions to conduct a zero signal from its input 74 on its output 43 in response to a digital signal on its input 75; and, in response to a digital signal on its input 76, the signal selector 54 conducts a signal representative of the value on its input 77, over its output 43. At times when the track enable input 46 is energized the controller 25 generates an analog signal on its output 22 corresponding to the signal on line 43 which signal corresponds to either zero or the value of the signal on its input 77. At times when the track enable input 46 is deenergized, the controller 25 generates a signal corresponding to the difference between the value of the signal from the load demand computer 10 on its input 78 and the actual megawatt output of the plant as detected by the detector MW. A component 76 which is shown in detail in FIG. 7, may be a standard analog component which conducts a signal at its output 63 which is equal to the value of an input signal on its line 68 less the value of an input signal on its line 70. The designation (plus) and (minus) adjacent the input 68 and 70 denote that the value of the signal on input 70 is algebraically subtracted from the value of the input signal on line 68. A difference component 71 is similar to the difference component 67 and conducts a signal on its output 66 that corresponds to the value of a signal on its input 72 less the value of a signal on its input 73.

The mode transfer circuitry 28 also includes mode select logic circuitry referred to as 80, which is shown in mode detail in FIG. 9; however, the mode select function 80 may be any conventional logic circuitry which functions as herein described. The logic 80 functions to energize its outputs 14, 15 and 16, selectively, to connect and disconnect the feedback controllers 23, 24 and 25 to the summing devices 12 and 13 in accordance with the desired mode of operation in response to the operation of the mode select pushbutton CPB, TPB or BPB. Also, the mode select logic 80 functions to energize its output 64 when the plant is in the turbine-follow mode, its output 81 when the plant is in the boiler-follow mode, and its output 46 when the plant is in the coordinated mode. The remaining components of the plant transfer circuitry 28 together with a detailed description of the method and system of the present invention will be explained in detail in connection with its operation prior to, during and subsequent to a transfer between turbine-follow, boiler-follow and coordinated control modes.

Assuming that the boiler-turbine power plant is operating in the turbine-follow mode, the mode select logic 80 is in a condition where the contact 17 in the output 20 of the feedback controller 23 is closed; and the contacts 18 and 19 in the outputs 21 and 22, respectively, of the controllers 24 and 25 are open. Thus, the feedforward signal on the output 11 of the load demand computer 10 is input through the summing device 13 and the manual/automatic transfer station 35 to the boiler master control 38 without correction. However, the feedforward signal on the output 11 to the summing device 12 is trimmed by a feedback error signal on the output 20 of the feedback controller 23 to either raise or lower the steam inlet valve position in accordance with the difference between the actual throttle pressure and the throttle pressure set point. Therefore, the firing rate of the boiler is determined solely in accordance with the value of the feedforward signal on the output 11; and any deviation in the throttle pressure set point is corrected by the raising or lowering of the steam inlet valves. At the same time, the output 64 of the mode select logic 80 is energized which results in the track enable input 45 being energized and a zero signal being selected by the signal selector 53 so that the output on line 42 is at zero potential, and the controller 24 is driven to have zero potential at its output. The input 45 to the controller 24 is energized by a circuit which includes line 64, OR gate 85, line 45 and the controller 24. Also, the controller 25 is driven to zero potential by a circuit which includes the deenergized output 46 from the logic 80, negative function 86, OR gate 87 and the track enable input 46; and by another circuit which includes OR gate 90, negative function 92 and input line 75 to the signal selector 54. A typical situation may exist with the plant operating in the turbine-follow mode wherein the value of the signal on the output 11 of the load demand computer 10 is at 50 percent load for example, and the error signal on line 20 from the feedback controller 23 may be at +10 percent for example. This condition results in a signal of 60 percent at the output 31 of the summing device 12 for input to the manual/automatic transfer station 32 and to the turbine master control 33 over line 39. The feedforward signal of 50 percent is also conducted to the summing device 13, which is uncorrected by the feedback controller 24 over line 34 to the manual/automatic station 35. In this condition the boiler master control is receiving a signal which corresponds to a 50 percent load while the turbine control is receiving a signal which corresponds to a 60 percent load in order to keep the system properly balanced.

The plant can be transferred between operating modes either manually or automatically in response to a predetermined contingency. The plant system, of course, in actual practice, is much more sophisticated in its structure on function; and for the sake of clarity in describing the inventions, only the function necessary to describe the present embodiment of the invention under manual transfer conditions is described and illustrated.

To transfer from the turbine-follow mode, previously described, to the boiler follow mode, the pushbutton BPB is depressed which activates a pulse generator 93 by a circuit which extends from BPB, and includes an OR gate 94. The activation of the pulse generator 93 produces a pulse on output 37, which in one practical embodiment of the invention is of 5 second duration. The entire transfer occurs during the existence of this 5

second pulse. However, it is to be understood that the entire transfer may occur in a much shorter period of time, such as in the order of 1 second, or shorter, for example. In response to the occurrence of the pulse on line 37 from the output of the pulse generator 93, the line 27 to the load demand computer 10 is energized which enables the load demand computer to accept and track the output signal present on the input 30. The manual transfer stations 32 and 35 in response to the energizing of the input 37 prevent any change in the value of the signal on lines 38 and 40 to the input of the turbine master control 33 and the boiler master control 36.

The occurrence of the pulse on line 37 also energizes inputs 95 96 and 97 to AND gates 98, 99 and 100 respectively. The AND gate 98 conducts in response to the occurrence of such pulse from the generator 93 because the other input 101 to the AND gate 98 is energized by the operation of the pushbutton BPB as shown in FIG. 1. The conducting of the AND gate 98 applies a digital signal on line 56 to the input of the signal selector 51, which selects the analog signal from the input 50 to be tracked by the load demand computer 10.

Also, the operation of the pushbutton BPB energizes an input 102 to the mode select logic 80 which deenergizes its output line 14 to open the contact 17 of the controller 23 to disconnect the feedback circuit from the summing device 12; and energizes its output line 15 to close the contact 18 in the output of the controller 24 to connect the feedback loop to the boiler master control 36 through the summer 13 and the manual/automatic station 35. While the input 102 of the mode select logic 80 is energized, all of the outputs 64, 81 and 46 of the mode select logic 80 are deenergized to represent that the plant is not in any one of its operating modes, but being transferred between modes. The deenergizing of the output line 64 from the mode select logic 80 removes the select zero signal command from the signal selector 53; and the deenergizing of the line 81 removes the select zero command over input 60 to the signal selector 52. The controller 25 remains in the same condition with respect to its input 46 and 43 as it was in the turbine follow mode.

To summarize the operation of the transfer system to this point in the description, the operation of the pushbutton BPB and the occurrence of the pulse at the output of the pulse generator 93 has governed the automatic/manual transfer station 32 and 35 to hold the signals on output 38 and 40 to their pre-transfer value; has operated the load demand computer 10 to track the pre-transfer signal on line 38 governing the turbine master control 33; and has disconnected and connected the feedback controllers 23 and 24 respectively. Also, the controller 24 is tracking the signal on input line 66 of the selector 53 from the difference function device 71. The device 71 is conducting a signal equal in value to the pre-transfer value of the signal to the boiler master control 36 less the value of the modified feedforward signal which was tracked prior to transfer.

Assuming the same quantitative situation to exist as previously described; that is, the trimmed feedforward signal to the turbine master control 53 in the turbine follow mode prior to transfer was equivalent to a 60 percent load, and the uncorrected feedforward signal to the boiler master control 36 was equivalent to a 50 percent load, the feedforward signal on line 11 during the transfer is equivalent to 60 percent instead of 50 percent. The output from the difference function de-

vice 71 is equal to -10 percent, which is conducted to the input 44 of the feedback controller 24, which drives the feedback controller 24 to produce a 10 percent signal at its output 21, which is input to the summing device 13. Thus, the value of the signal at the output 34 of the summing device 13 is equal to 50 percent which is the same value present previous to the beginning of the transfer; and the output signal on line 31 of device 12, to the turbine master control equal to a 60 percent load signal, which is the pre-transfer value of such signal. At the termination of the 5 second pulse from the generator 93, the transfer is deemed complete; and the system is placed in the following condition.

A negative function 106 to the input of the mode select logic 80 causes the output line 81 of the mode select logic 80 to be energized which is representative of the plant being in the boiler-follow mode. The signal on the output line 81 causes the signal selector 52 to conduct a zero signal on its output 41 to drive the signal on the output 20 of the controller 23 to zero in preparation for the next transfer. Also, AND gate 83 ceases to conduct which deenergizes the track enable input 45 of the controller 44 so that the boiler feedback controller 44 now responds to an error signal corresponding to the actual throttle pressure and the set point throttle pressure for the boiler-follow mode.

To transfer to the coordinated mode of operation the pulse generator 93 is activated in response to the operation of the pushbutton CPB, to generate the five second pulse to hold the input signal to the control mechanisms 33 and 38 at their pre-transfer value in the same manner as described in connection with the transfer from the turbine-follow to the boiler-follow mode. The mode select logic 80 is energized through input 107, which energizes the output line 14, deenergizes the output line 15, and energizes the output line 16 so that contacts 17 and 19 are closed and contact 18 is opened in the outputs 20, 21 and 22 respectively of the feedback controllers 23, 24 and 25 to connect both the megawatt and turbine throttle pressure feedback loops to the summing devices 13 and 12 respectively.

During transfer to the coordinated mode, the track enable input 27 to the LDC computer 10, the track enable input 44 to the feedback controller 23, and the track enable input 45 to the feedback controller 25 is energized. The circuit for energizing the track enable input 27 includes line 37 at the output of the pulse generator 93. The circuit for energizing the track enable input 44 includes the output of the AND gate 100 and the OR gate 110. The circuit for energizing the track enable input 46 includes the output of the AND gate 100, line 108, and OR gate 87.

The load demand computer 10 during this transfer tracks the analog signal on input line 57, which signal is connected to the megawatt detector MW and is equal in value to the actual megawatt output of the turbine. The presence of a signal on line 56C at the output of the AND gate 100 selects the signal on the input 57. The controller 23 tracks the analog signal occurring on input 63 to the selector 52 from the difference device 57 during transfer to the coordinated mode. The circuit for selecting the input 63 includes the output of the AND gate 100 and the input 61 to the selector 52. Also, during the transfer to the coordinated mode the controller 25 tracks the analog signal on the input 77 to the signal selector 54. The circuit for selecting the signal on the input 77 includes the output of the AND gate

100, line 108, the OR gate 90, and the input 76 to the signal selector 54.

Assuming that in the boiler-follow mode, the value of the signal at the input to the boiler master control previous to the transfer is equivalent to a 60 percent load demand; and assuming that the value of the feedforward signal to the turbine master control 33 previous to the transfer is equivalent to a 50 percent load demand, then the same signal value on each of the inputs to the turbine and boiler master control must be 50 and 60 percent after the transfer. In the present example of the transfer to the coordinated mode, it is assumed that the actual megawatt signal value as detected by the detector MW is equivalent to a 70 percent load. Therefore, during the transfer, the value of the signal on the output 11 of the load demand computer 10 becomes equal to the actual megawatt signal value which is 70 percent. The difference device 67 operates to subtract the 70 percent megawatt signal from the 50 percent uncorrected pre-transfer feedforward signal resulting in a -20 percent signal on the input 63, which is tracked by the feedback controller 23. Thus, the summing device 12 algebraically adds the 70 percent megawatt signal on the output 11 and the -20 percent signal on the output 20 of the controller 23 resulting in a 50 percent load signal on the input 31 to the manual/automatic transfer station 31, which is identical to the value of the pre-transfer signal. The pre-transfer value of the signal to the boiler master control 36 is 60 percent, and the actual megawatt output signal on line 11 is 70 percent. Therefore, the difference device 71 subtracts the 70 percent signal which is input on line 73 from the 60 percent signal which is input on line 72 to the difference device 71. Thus, the value of the signal that is tracked by the controller 25 is equal to -10 percent. The summing device 13 during this transfer has a 70 percent signal input from the line 11 and a -10 percent signal from the output 22 of the controller 25, which results in a signal having a 60 percent value on the input 34 to the manual/automatic transfer station 35. Therefore, the pre-transfer value of the input signal to the boiler master control 36 is identical to the value of the signal on the line 34 which is summed by the summing device 13 during the transfer.

At the end of the five second period, the output pulse from the generator 93 ceases which releases the hold on the manual/automatic station 32 and 35. The gate 100 ceases to conduct which removes the signal from the track enable input to the load demand computer 10, the feedback controller 23, and the feedback controller 25. Thus, the load demand computer 10 may be operated through its remote control device 58 or its manual control device 26 for varying the value of the feedforward signal on the output 11; the feedback controller 23 is now generating an error signal corresponding to the value between the throttle pressure set point and the actual throttle pressure; and the feedback controller 25 is generating an error signal corresponding to the difference between the feedforward signal on the output 11 and the actual megawatt output of the plant.

To transfer from the coordinated mode to the boiler-follow mode, the pushbutton BPB is operated to generate the 5 second pulse, as described in connection with the other transfers. Also, the feedback controller 25 and the feedback controller 23 are disconnected from the summing devices 12 and 13 while the feedback controller is connected to the summing device 13 by the energizing and deenergizing of the appropriate out-

puts 14, 15 and 16 of the logic 80 as previously described. Assuming that prior to the transfer the signal that is input to the turbine master control 33 is 50 percent, and the signal input to the boiler master control 36 is 60 percent, such signals are held at their pre-transfer value in response to the presence of the 5 second pulse in the same manner as previously described. The input 56 to the signal selector 61 is energized by the previously described circuit which governs the load demand computer 10 to track the signal on its input 50 which corresponds to the pre-transfer value of the demand signal to the turbine master control 33 which is in the present example 50 percent. Therefore, the signal on the output 11 is changed to be equal to a 50% signal for controlling the turbine master control 33 at the termination of the transfer in the same manner as described in connection with the previous examples. The boiler feedback controller 24 is governed to track an output equivalent to 10 percent which is the tracked signal of 50 percent on the output 11 subtracted from the pre-transfer signal of 60 percent on the input 72 of the difference amplifier 71. Thus, the 50 percent signal and the 10 percent signal are added by the summing device 13 to provide a signal equivalent to a 60 percent demand which is the same value of the demand signal present previous to the transfer. The disconnected controllers 23 and 25 are driven to their zero condition at the termination of the transfer by the previously described circuits.

FIG. 3 schematically shows the primary functions of the load demand computer insofar as they affect the method and system of the present invention. For example, the energizing of the track enable input 27 conditions AND gates 115 and 116 to operate a conventional up/down counter 117, which in turn operates a digital-to-analog converter 118 to generate the analog signal on the output 11. The selected track signal is input to comparators 120 and 121 which is compared to the signal on the output 11 for either operating the up/down counter 117 to either increase or decrease the value of the signal. The manual control device 26 operates the up/down counter 117 directly through OR gates 122 and 123.

FIG. 4 illustrates schematically the track signal selector 51 which selects either the actual megawatts, the pre-transfer value of the boiler demand signal or the pre-transfer value of the turbine demand signal to be conducted over its output 30 in response to the energizing of either its input for entering the coordinated, turbine-follow or boiler-follow mode of operation. For example, the energizing of the input 56C closes contacts 130 and 131 of a relay 132 to conduct the signal on input 57 to the output line 30. The signal selectors 52, 53 and 54 may have the same type of an arrangement as the signal selector 51.

FIG. 5 illustrates schematically a feedback controller, such as the controller 23. When the track enable input 44 is energized, a relay 140 is closed which conducts the analog signal from the line 41 through the controller circuitry to the output line 20. When the input line 44 is deenergized, a relay 141 is energized which conducts the error signal between the actual throttle pressure and the set point throttle pressure to the output 20. Regardless of the period for integrating the time constant, the controller output is immediate when the track enable input is energized. Although the other controllers differ with respect to the integration of their time constant, they are all assumed to be simi-

larly constructed. For example, the turbine throttle pressure controller 23 in one practical embodiment integrates its time constant in 15 to 20 seconds, for example. The megawatt controller 25 integrates its time constant in 5 minutes, for example; and the boiler throttle pressure controller 24 integrates its time constant in approximately 3 minutes, for example.

FIG. 6 is a schematic arrangement of a conventional summing device, such as the summing device 12 wherein the analog signals on line 11 and 20 are summed to provide the output on lines 31.

FIG. 7 is a typical difference device, such as 67, for example, wherein the analog input on line 70 is subtracted from the analog signal on line 68 to generate the difference on the output 63 in a conventional manner.

FIG. 8 is a manual/automatic transfer station, such as 32, where an input signal on the line 37 holds the output signal on line 38, for example, by inhibiting the operation of an up/down counter 150. When the line 37 is deenergized, a signal on the input 31 operates the up/down counter 150, which operates a digital-to-analog converter 151 to provide the proper analog signal on the output 38. The manual/automatic station includes various logic in clocks to perform other functions including switching over from automatic to manual control of the turbine or the boiler, as the case may be, by the operation of the panel buttons referred to at 152.

FIG. 9 illustrates schematically one form of the mode select logic circuitry, which includes the various logic gates to energize the various outputs in response to the operation of the pushbuttons BPB, TBP and CBP in the manner described in connection with the operation of the system. Flip-flop circuits 160, 161 and 162 permit the operator to momentarily depress the pushbutton to initiate transfer.

Although a description of the system has been described in connection with a transfer from the turbine-follow to boiler-follow mode, from the boiler-follow to the coordinated mode, and from the coordinated mode to the boiler-follow mode, such description renders opposed transfer between the other of the modes.

To summarize the operation of the system and method of the present embodiment of the invention, the initiation of a transfer generates a pulse of 5 second duration from the output of the generator 93. The presence of the pulse prevents an increase or a decrease in the outputs of the transfer stations 32 and 35 to the input of the boiler and turbine control apparatus 36 and 33. The feedback controllers 23, 24, and 25 are connected and disconnected by the mode select logic 80 depending on the mode that the system is entering. The track enable input to the computer 10 is energized; and the track enable input to the feedback controllers which are to be placed in service upon termination of the transfer are energized. The feedforward signal from the load demand computer 10 is increased or decreased to equal the analog signal selected by the signal selector 51. This signal is equal to the pre-transfer or held output of the manual/automatic station which will receive an uncorrected feedforward signal at termination of the transfer. When transferring to the coordinated mode, the signal is equal to the actual megawatt output of the plant.

The feedback controllers 23, 24 or 25, depending on the mode the system is entering, tracks a selected signal input to its associated signal selector 52, 53, and 54. This tracked signal is equal to the held output on its as-

sociated transfer station 32 and 35 less the tracked signal generated by the computer 10. The tracked output signal from the feedback controller is summed with the tracked signal from the computer 10 by its associated summing device 12 and 13.

At the end of the 5 second period the pulse from generator 93 terminates which permits the manual/automatic stations 32 and 35 to respond to variations in their inputs 31 and 34, and the tracking function of the inservice feedback controller is removed.

It is understood that the inventive features of the system and method of the present invention may be implemented with various types of apparatus and components, and the particular circuit is illustrative only. Variations within the spirit and scope of the invention may be made by those skilled in the art.

What is claimed is:

1. A system for transferring a boiler turbine power plant from one operating mode to another rapidly without disturbing the plant process wherein predetermined selected in service feedback loops trim a feedforward signal for controlling the boiler and turbine in each operating mode and at least one feedback loop is put in service for changing operating modes, said system comprising

a turbine control apparatus for controlling turbine inlet valve position in accordance with the value of an input signal,

a boiler control apparatus for controlling boiler firing rate in accordance with the value of an input signal, means to generate a feedforward signal representative of desired plant operation connected electrically to input the feedforward signal to the boiler and turbine control apparatus in parallel,

at least one feedback loop for each control apparatus to generate an output signal,

first circuit means including each feedback loop to modify the value of the input signal to the boiler and turbine apparatus in accordance with the output signal value of its associated feedback loop that is in service for a distinct operating mode,

mode transfer selection means effective when activated to govern the turbine and boiler control apparatus to be unresponsive to a change in the value of either a feedforward or feedback signal to prevent any change in turbine valve position and boiler firing rate during a mode transfer,

second circuit means including the feedforward signal generating means governed by the activation of the transfer means to modify the generated feedforward signal to be representative of a selected value in accordance with the operating mode selected by the mode transfer means,

third circuit means governed by the activated transfer means to control each feedback loop put in service in accordance with the selected operating mode to generate a feedback output signal for the first circuit means having a value to modify the input signal for the turbine and boiler control apparatus to be representative of the value of the turbine and boiler control apparatus input signal upon activation of the transfer means, and

means deactivating the transfer means to render the boiler and turbine control apparatus responsive to their respective input signal from the signal generating means as modified by the first circuit means.

2. A system according to claim 1 wherein the selected value of the modified feedforward signal by the

second circuit means is representative of the actual power output of the plant while the transfer selection means is activated.

3. A system for transferring from one operating mode to another according to claim 1 wherein at least one feedback loop is taken out of service and another feedback loop is put in service to change operating modes, and wherein the selected value of the modified feedforward signal is representative of the value of the input signal to the control apparatus having its associated feedback loop being taken out of service by the mode transfer selection means.

4. A system according to claim 1 wherein the first circuit means includes a summing device for algebraically adding the feedforward signal and the output of the in service feedback loop.

5. A system according to claim 1 further comprising an analog signal generating device for each control apparatus responsive to the signal from the first and second circuit means to govern the value of the input signal for its associated control apparatus, and each said device includes means responsive to the activation of the transfer selection means to hold the output of the analog signal generating device stationary while the transfer selection means is activated.

6. A system according to claim 1 wherein the transfer selection means and the transfer deactivating means includes a pulse generator for generating a selected pulse of a predetermined time duration, and the transfer selection means is activated during the time duration of the generated pulse only.

7. A system according to claim 6 wherein the duration of the generated pulse does not exceed 5 seconds.

8. A system according to claim 1 wherein each feedback loop includes a proportional plus integral controller, and the third circuit means includes a difference function device for each control apparatus governed by input signals representing the value of the input signal of its associated control apparatus upon activation of the transfer selection means and the value of the feedforward signal modified by the second circuit means to conduct a difference signal, and the controller is governed by the value of the difference signal while the transfer selection means is activated to generate the value of such difference signal at its output.

9. A system for transferring from one operating mode to another rapidly and without disturbing the plant process of a boiler-turbine power plant, comprising

a load demand signal generator operative to generate an output signal having a value corresponding to a desired plant load, said device having means to increase and decrease the output signal in accordance with the value of a selected tracking signal,

a turbine control apparatus and a boiler control apparatus, each operative to govern the operation of the boiler and the turbine respectively in accordance with the value of an input signal,

a throttle pressure feedback controller for each control apparatus operative to generate an error signal representative of the required change in the desired load signal for its associated apparatus to operate its respective turbine and boiler to maintain a predetermined throttle pressure, each said controller also having means to generate an error signal in accordance with the value of a selected tracking signal,

a summing device for each control apparatus connected at one input to receive the error signal from

its associated feedback controller and connected at another input to receive the desired load signal from the generator, each said device being operative to generate an output signal corresponding to the algebraic sum of the value of the input signals, an analog signal generator for each control apparatus connected at its input to the output signal of its associated summing device, said signal generator being operatively connected to generate a demand signal for its associated apparatus in accordance with the value of the signal from the summing device, each said device also including a holding means when activated to prevent the output signal to its associated control apparatus from responding to a change in its input signal,

a difference function device for each control apparatus having one input connected electrically between the output of its associated summing device and another input connected to the output of the load demand generator, each said device being operative to generate at its output a signal representative of the value of the signal at its one input less the value of the signal on its other input,

transfer means operative when activated to initiate a transfer to a selected operating mode,

means responsive to the activation of the transfer means to activate the holding means of each analog signal generator,

means governed by the activation of the transfer means to connect and disconnect selected feedback controllers to and from their respective summing devices in accordance with the selected mode,

means governed by the activation of the transfer means to increase or decrease the desired load signal at the input to each summing device to track the value of the signal at the output of the analog signal generator for the control apparatus disconnected from the output of a feedback controller upon deactivation of the transfer means,

means governed by the activation of the transfer means to operate the feedback controller to be connected to its summing device in accordance with a selected mode to track the signal at the output of the difference device, and

means deactivating the transfer means, whereby the signal to the input of each analog device upon deactivation of the transfer means is representative of the input signal upon activation of the transfer means.

10. A system according to claim 9 further comprising a megawatt feedback controller for the boiler control apparatus operative to generate an error signal representative of the required change in the load signal for the boiler control apparatus to operate the boiler control apparatus to govern the turbine to maintain a predetermined power output, said feedback controller also having means to generate an error signal in accordance with the value of a selected tracking signal,

means governed by the activation of the transfer means to connect the throttle pressure feedback controller to the summing device associated with the turbine control apparatus and the megawatt feedback loop to the summing device associated with the boiler control apparatus as the selected mode,

means governed by the activation of the transfer means for the selected mode to increase or de-

crease the desired load signal in accordance with the value of the actual power output of the plant, and

means governed by the activation of the transfer means for the selected mode to operate the connected throttle pressure controller and the megawatt pressure controller to track the signal at the output of its associated difference device.

11. A method of transferring rapidly from one to another of at least two modes of operation in a boiler-turbine power plant without disturbing the plant process wherein a control signal representative of desired plant load is generated to control in parallel the boiler portion of the plant and the steam turbine portion of the plant in both of the modes and a feedback loop modifies the control signal to the boiler only in one of the modes and a feedback loop modifies the control signal to the turbine only in the other mode, said method comprising

holding the load demand signals to both the boiler and turbine at their pre-transfer value to prevent a change in their value during the transfer,

changing the connection of the feedback loops from one of the portions of the plant to the other,

changing the desired load signal to be representative of the value of the pre-transfer modified demand signal for one of the portions of the plant

generating a feedback signal for the other portion representative of the value of the pre-transfer load demand signal to said portion less the value of the desired load signal, and

releasing the hold on the load demand signals to both the boiler and turbine,

whereby the load demand signal to both the boiler and turbine is the same before and after the changing of the feedback loops from one to the other of the elements.

12. A method of transferring from one operating mode to another rapidly and without disturbing the plant process of a boiler turbine power plant, wherein selected feedback loops trim a feedforward signal to provide a load demand signal for controlling the boiler and turbine in each operating mode, said method comprising

holding the load demand signal to the boiler and turbine at a constant value during the transfer,

changing the feedforward signal to be representative of a selected value,

generating a feedback signal having a value, which when summed the feedforward signal is representative of the value of the load demand signals held during the transfer,

summing the generated feedback signals with the changed feedforward signal for the loops to be put in service upon termination of the transfer, and

releasing the hold on the load demand signals to terminate the transfer.

13. A method according to claim 12 wherein the changed feedforward signal is representative of the actual power output of the plant at times when the transfer effects the trimming of the load demand signal to both the turbine and boiler.

14. A method according to claim 12 wherein the changed feedforward signal is representative of the pre-transfer trimmed load demand signal at times when the transfer effects the trimming of the other of the boiler turbine load demand signals only.

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15. A system for transferring from one operating mode to another rapidly and without disturbing the plant process of a boiler turbine power plant wherein selected connected feedback loops trim a feedforward signal to provide a load demand signal for controlling the boiler and turbine in each operating mode; said system comprising

- means to initiate a transfer from one mode to another,
- means responsive to the initiation of a transfer to hold the load demand signals to the boiler and turbine at a constant value during the transfer,

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- means governed by the initiation of a transfer to change the feedforward signal to be representative of a selected value,
- means to generate another signal for each feedback loop to be connected in accordance with the selected operating mode, said signal having a value which when summed with the changed feedforward signal is representative of the value of the load demand signal held at the constant value,
- means to sum the feedforward signal and the other feedback generated signal for the selected connected loops, and
- means to release the hold on the load demand signal at termination of the transfer.

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