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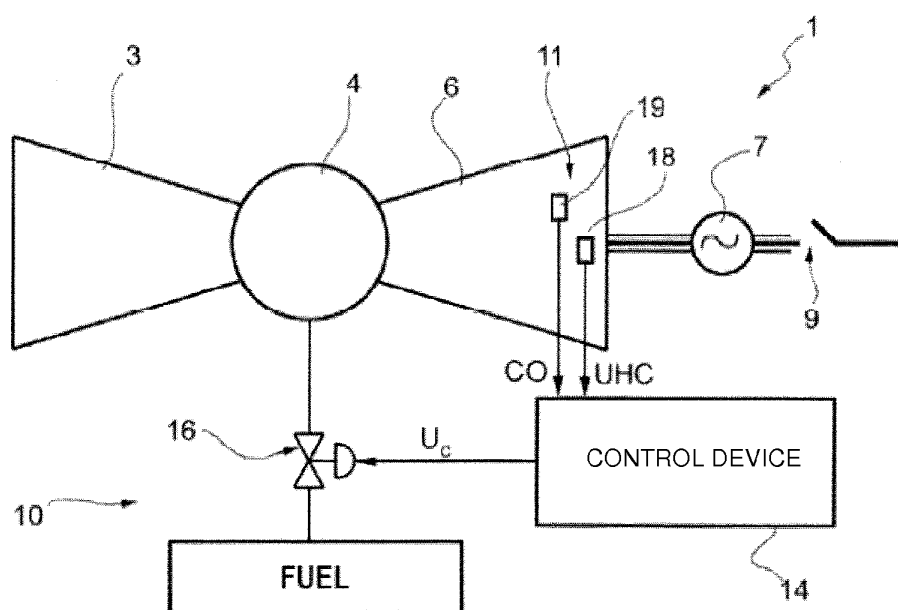
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(54) **Control method for controlling the supply of fuel to a gas turbine plant and gas turbine plant**

(57) A control method for controlling the supply of fuel to a gas turbine plant (1) provided with a gas turbine (6) and a combustion chamber (4) supplied with a fuel/oxidizer mixture, includes the steps of:
- at the exhaust (12) of the gas turbine (6), detecting at least a first parameter related to the unburned fuel concentration (UHC);

centration (UHC);
- at the exhaust (12) of the gas turbine (6), detecting at least a second parameter related to the specific energy produced by the combustion (CO);
- calculating a fuel flow rate (Q_{TOT}) to be supplied to the combustion chamber (4) on the basis of the first parameter (UHC) and of the second parameter (CO).

FIG. 1



Description

[0001] The present invention relates to a control method for controlling the supply of fuel in a gas turbine plant and to a gas turbine plant.

[0002] Gas turbine plants of the known type comprise a combustion chamber, which is supplied with a fuel, generally gas.

[0003] The amount of gas supplied to the combustion chamber is calculated by a fuel supply control device.

[0004] Over the past years, the design of fuel supply control devices has mainly focused on the reduction of pollutants by controlling flame temperature in the combustion chamber, neglecting overall plant efficiency in some cases.

[0005] Indeed, it often occurs, above all under conditions of power generated in variable rate mode, that an amount of fuel higher than the amount which may actually be burnt is supplied to the combustion chamber. This determines wasting of fuel and consequent worsening of overall plant efficiency.

[0006] It is thus an object of the present invention to provide a control method for controlling the supply of fuel which is free from the drawbacks disclosed above; in particular, it is the object of the present invention to provide a control method which is capable of optimizing fuel consumption and increasing the overall efficiency of the plant.

[0007] In accordance with such objects, the present invention relates to a control method for controlling the supply of fuel to a gas turbine; the plant comprising a gas turbine and a combustion chamber supplied with a mixture of fuel and oxidizer; the method being characterized by comprising the steps of:

- at the exhaust of the gas turbine, detecting at least a first parameter related to the unburned fuel concentration;
- at the exhaust of the gas turbine, detecting at least a second parameter related to the specific energy produced by the combustion;
- calculating a fuel flow rate to be supplied to the combustion chamber on the basis of the first parameter and of the second parameter.

[0008] It is a further object of the present invention to provide an efficient gas turbine plant in which fuel consumption is optimized.

[0009] In accordance with such objects, the present invention relates to a gas turbine plant comprising a gas turbine, a combustion chamber supplied with a mixture of fuel and oxidizer, and a control device for controlling the supply of fuel to the gas turbine plant; the control device being configured:

- to detect a first parameter related to the unburned fuel concentration at the exhaust of the gas turbine at least;
- to detect at least a second parameter related to the specific energy produced by the combustion at the exhaust of the gas turbine;
- to calculate a fuel flow rate to be supplied to the combustion chamber on the basis of the first parameter and of the second parameter.

[0010] Further features and advantages of the present invention will become apparent from the following description of a non-limitative embodiment thereof, with reference to the figures of the accompanying drawings, in which:

- figure 1 is a diagrammatic view of a gas turbine plant according to the present invention;
- figure 2 is a block chart of a detail of the plant in figure 1;
- figure 3 is a block chart of a detail in figure 2;
- figure 4 is a diagrammatic view of a gas turbine plant according to a second embodiment of the present invention;
- figure 5 is a block chart of a detail of the plant in figure 4;
- figure 6 is a block chart of a detail in figure 5.

[0011] In figure 1, reference numeral 1 indicates as a whole a gas turbine plant for the production of electricity.

[0012] Plant 1 comprises a compressor 3, a combustion chamber 4, a gas turbine 6 and a generator 7, which converts the mechanical power supplied by turbine 6 into electric power PEL to be supplied to an electric network 8. The electric network 8 being connected to generator 7 by means of a switch 9.

[0013] Plant 1 further comprises a supply circuit 10 configured to supply the fuel to the combustion chamber 4, a sensor assembly 11 arranged at the exhaust 12 of turbine 6 and a control device 14 for controlling the supply of fuel to the combustion chamber 4 on the basis of the data detected by the sensor group 11.

[0014] In particular, the supply circuit 10 is provided with at least one control valve 16, which is controlled by the control device 14 by means of a control signal U_c for supplying a flow rate of fuel Q_{TOT} , generally gas, to the combustion chamber 4.

[0015] The sensor assembly 11 comprises at least a first sensor 18 configured to detect a first parameter indicating the amount of unburned fuel and at least a second sensor 19 configured to detect a parameter indicating the specific

energy produced by the combustion. Thereinafter, "specific energy produced by the combustion" means the amount of energy developed by the mass unit of the mixture of fuel and oxidizer in the combustion chamber 4.

[0016] In the non-limiting example described and shown herein, the first parameter is the concentration of unburned hydrocarbons UHC present in the exhaust gas 12.

[0017] Preferably, the first sensor 18 is a Flame Ionization Detector (FID) configured to detect the concentration of unburned hydrocarbons in the analyzed gas. In particular, the first sensor 18 is configured to detect the amount of UHC (in mg) present in a normal cubic meter (in Nm³) of gas taken from the exhaust 12 of turbine 6. "Normal cubic meter" means a cubic meter of gas under normal pressure (1013 bar) and temperature (0° C) conditions.

[0018] A variant (not shown) requires the first sensor 18 to be an optical sensor capable of detecting the concentration of UHC by means of a sensor installed on the exhaust pipe of turbine 6 and capable of measuring the UHC concentration "in situ".

[0019] In the non-limiting example described and shown herein, the second parameter is the concentration of carbon monoxide CO present in the exhaust gas 12.

[0020] The second sensor 19 is preferably an infrared light detector (commonly called NDIR: Non-Dispersive Infrared Sensor), which is simply a spectroscope configured to detect the concentration of CO in the analyzed gas. In particular, the second sensor 19 is configured to detect the amount of CO (in mg) present in a normal cubic meter (in Nm³) of gas taken from the exhaust 12 of turbine 6.

[0021] A variant (not shown) requires the second sensor 18 to be an optical sensor capable of detecting the concentration of CO by means of a sensor installed on the exhaust pipe of turbine 6 and capable of measuring the CO concentration "in situ".

[0022] The control device 14 is configured to calculate the control signal U_c on the basis of the parameters detected by the sensor assembly 11. In particular, the control device 14 is configured to calculate a flow rate Q_{TOT} to be supplied to the combustion chamber on the basis of the first parameter correlated to the combustion of unburnt hydrocarbons (UHC) and of the second parameter correlated to the concentration of carbon monoxide (CO), detected by the first sensor 19 and by the second sensor 19, respectively.

[0023] With reference to figure 2, the control device 14 comprises a calculation block 20 configured to calculate the minimum basic flow rate Q_{MIN_BASE} , a configuration block 21 configured to calculate the variation of the minimum flow rate ΔQ_{MIN} , a subtractor node 22, a calculation block 23 configured to calculate a flow rate contribution ΔQ , an adder node 24 and a valve control block 25 configured to calculate the control signal U_c on the basis of an input flow rate Q_{TOT} .

[0024] The calculation block 20 is configured to calculate the minimum basic flow rate Q_{MIN_BASE} to be supplied to the combustion chamber 4 in accordance with control logics which are not the object of the present invention.

[0025] The control block 21 is configured to calculate the variation of the minimum flow rate ΔQ_{MIN} on the basis of the parameters detected by the sensor assembly 11.

[0026] With reference to figure 3, the calculation block 21 comprises a first error calculation block 30, a second error calculation block 31, a first normalization block 32, a second normalization block 33, a first multiplier node 34, a second multiplier node 35, a subtractor node 37 and a filtering module 40.

[0027] In detail, the first error calculation block 30 is configured to calculate a first error between the value of the parameter indicating the amount of unburned hydrocarbons UHC detected by the first sensor 18 and a first reference value UHC_{REF} .

[0028] The first error UHC_{ERR} is a significant parameter of the excess fuel amount which cannot be burnt in the combustion chamber 4.

[0029] The first reference value UHC_{REF} varies according to the type and dimensions of plant 1. In the non-limiting example described and shown herein, UHC_{REF} is equal to 0.2 mg/Nm³.

[0030] The first error UHC_{ERR} is thus integrated and normalized in the first normalization block 32 so as to provide a first normalized error $UHC_{ERR-NORM}$ which may be compared with other parameters. In the non-limiting example described herein, the first normalization block 32 is configured to convert the first error UHC_{ERR} into a non-dimensional numeric value ($UHC_{ERR-NORM}$) from 0 to 100.

[0031] The first normalized error $UHC_{ERR-NORM}$ is then supplied to the first multiplier node 34 to be multiplied by a first coefficient K_{UHC} so as to output a first normalized, weighted error $UHC_{ERR-NORM-KUHC}$. The first coefficient K_{UHC} has a predefined value, determined according to the weight to be attributed to the first normalized error $UHC_{ERR-NORM}$. In the non-limiting example described and shown herein, the first coefficient K_{UHC} is preferably equal to 1.

[0032] The second error calculation block 31 is configured to calculate a second error CO_{ERR} between the value of the parameter indicating the amount of carbon monoxide CO detected by the second sensor 19 and a second reference value CO_{REF} . The second error CO_{ERR} is a significant parameter of the excessive cooling of the combustion process in the combustion chamber 4. The second reference value CO_{REF} varies according to the type and dimensions of plant 1. Preferably, the second reference value CO_{REF} is equal to 3 mg/Nm³.

[0033] The second error CO_{ERR} is thus integrated and normalized in the second normalization block 33 so as to provide a second normalized error $CO_{ERR-NORM}$ which may be compared with other parameters. In the non-limiting

example described herein, the second normalization block 33 is configured to convert the second error CO_{ERR} into a non-dimensional numeric value ($CO_{ERR-NORM}$) from 0 to 100.

[0034] The second normalized error $CO_{ERR-NORM}$ is then supplied to the second multiplier node 35 to be multiplied by a second coefficient K_{CO} so as to output a second normalized, weighted error $CO_{ERR-NORM-KCO}$. The second coefficient K_{CO} has a predefined value, determined according to the weight to be attributed to the second normalized error $CO_{ERR-NORM}$. In the non-limiting example described and shown herein, the second coefficient K_{CO} is preferably equal to 1.

[0035] The first normalized, weighted error $UHC_{ERR-NORM-KUHC}$ and the second normalized, weighted error $CO_{ERR-NORM-KCO}$ are supplied to the subtractor node 37, which essentially carries out the following operation:

$$DIFF = UHC_{ERR-NORM-KUHC} - CO_{ERR-NORM-KCO}$$

[0036] The difference signal DIFF thus obtained may be zero when the contributions given by the excess of fuel and by the excessive cooling of the combustion are equal; positive in the presence of fuel in excess; negative when the cooling action given by the excess of oxidizer in the mixture of fuel and oxidizer is dominant.

[0037] The difference signal DIFF is thus supplied to the filtering module 40, which is configured to eliminate the negative values of the difference signal DIFF and to limit the positive values of the difference signal DIFF under a maximum value so as to supply the variation of the minimum flow rate ΔQ_{MIN} which will be supplied to the subtractor node 22 in figure 2.

[0038] Preferably, the maximum value is equal to the minimum flow rate Q_{MIN} calculated by the calculation block 20.

[0039] Thereby, if the difference signal DIFF is zero (i.e. the contributions of the excess of fuel and of the excessive cooling of the combustion are equal), the variation of minimum flow rate ΔQ_{MIN} will be zero and therefore no correction to the minimum flow rate value Q_{MIN} will be made.

[0040] If the different signal DIFF is negative, instead, the minimum flow rate ΔQ_{MIN} will be zero, and therefore no correction to the minimum flow rate Q_{MIN} value will be made.

[0041] If instead the difference signal DIFF is positive (i.e. in the presence of excess of fuel), the variation of the minimum flow rate ΔQ_{MIN} will be equal to the different signal DIFF if the difference signal DIFF is lower than the maximum value, while it will be equal to the maximum value if the different signal DIFF is higher than the maximum value.

[0042] With reference to figure 2, the variation of the minimum flow rate ΔQ_{MIN} is supplied to the subtractor node 22, which substantially carries out the following operation:

$$Q_{MIN} = Q_{MIN_BASE} - \Delta Q_{MIN}$$

[0043] The minimum flow rate Q_{MIN} is thus supplied to the adder node 24, which adds the minimum flow rate Q_{MIN} and the flow rate contribution ΔQ . The flow rate contribution ΔQ is calculated by the calculation block 23 in accordance with control logics which are not the object of the present invention and mainly based on the power, speed and turbine exhaust gas temperature request.

[0044] In essence, the adder node 24 outputs a fuel flow rate $Q_{TOT} = Q_{MIN} + \Delta Q$, which is supplied to the valve control block 25 for controlling the control signal U_c which regulates the opening degree of the control valve 16.

[0045] The control device 14 is advantageously configured so as to reduce the fuel flow rate Q_{TOT} supplied by the combustion chamber 4 when an excess of fuel condition occurs with respect to that which can be instantaneously burnt.

[0046] In particular, the control device 14 is configured to calculate the amount of fuel which must be subtracted (i.e. the variation of the minimum flow rate ΔQ_{MIN}) to avoid excess of fuel and to optimize the overall performance of plant 1.

[0047] Figure 4 shows a second embodiment of the present invention in which the same reference numbers used in figures 1-3 are kept to indicate similar elements.

[0048] According to such a variant, the sensor assembly 111 also comprises, in addition to the first sensor 18 and to the second sensor 19, a third sensor 119 configured to detect a parameter indicating the amount of oxygen O_2 present in the exhaust gas 12 of turbine 6.

[0049] Preferably, the third sensor 119 is an infrared light detector (commonly called NDIR: Non-Dispersive Infrared Sensor), which is simply a spectroscope configured to detect the concentration of CO in the analyzed gas. In particular, the third sensor 119 is configured to detect the amount of CO (in mg) present in a normal cubic meter (in Nm^3) of gas taken from the exhaust 12 of turbine 6.

[0050] With reference to figure 2, the parameter indicating the amount of oxygen O_2 present in the exhaust gas of turbine 6 detected by the third sensor 120 is supplied to the control device 114. The control device 114 differs from the control device 14 of the first embodiment just for the presence of a calculation block 121, which is configured to calculate

the variation of minimum flow rate ΔQ_{MIN} on the basis of the parameters detected by the first sensor 18, the second sensor 19 and the third sensor 119.

[0051] With reference to figure 3, the calculation block 121 differs from the calculation block 21 substantially for the presence, downstream of the filtering module 40, of a third error calculation block 125 and of a saturation block 126.

[0052] Furthermore, in this second embodiment, the maximum value MAX of the filtering module 40 is not equal to the minimum basic flow rate $Q_{\text{MIN-BASE}}$, but is equal to a value established beforehand. In the non-limitative example described and shown herein, the maximum value MAX is equal to 21. Such a value corresponds to the limit condition in which there is no combustion due to excess of oxidizer.

[0053] The third error calculation block 125 is configured to calculate a first error $O_{2\text{ERR}}$ between the value of the parameter indicating the amount of O_2 detected by the third sensor 119 and the value of the filtered difference signal $\text{DIFF}_{\text{FILT}}$ output by the filtering module 40.

[0054] The third error $O_{2\text{ERR}}$ is a significant parameter of the imbalance in the fuel/oxidizer ratio.

[0055] The third error $O_{2\text{ERR}}$ is then integrated and saturated between 0 and the value of the minimum basic flow rate $Q_{\text{MIN-BASE}}$ so as to output the variation of the minimum flow rate ΔQ_{MIN} which will be supplied to the subtractor node 22 in figure 2.

[0056] Advantageously, in this second embodiment, a parameter indicating the fuel/oxidizer ratio (i.e. O_2) is also controlled in order to obtain an optimal combustion, in which the combustion process is maintained, and an optimal temperature, and in which only the amount of fuel that it may actually burn is supplied to the combustion chamber.

[0057] Effects obtained by injecting the strictly required amount of fuel are an improvement of the thermal machine efficiency with saving of fuel, an increase of the load gradient because the combustion process of the injected fuel is accelerated, a reduction of the UHC emissions and a reduction of CO emissions, especially at low loads by controlling cooling.

[0058] It is finally apparent that changes and variations may be made to the plant described herein without departing from the scope of the appended claims.

Claims

1. Control method for controlling the supply of fuel to a gas turbine plant (1); the plant (1) comprising a gas turbine (6) and a combustion chamber (4) fed with a mixture of fuel and oxidizer; the method being **characterized by** comprising the steps of:

- detecting at the exhaust (12) of the gas turbine (6) at least a first parameter related to the unburned fuel concentration (UHC);
- detecting at the exhaust (12) of the gas turbine (6) at least a second parameter related to the specific energy produced by the combustion (CO);
- calculating a fuel flow rate (Q_{TOT}) to be supplied to the combustion chamber (4) on the basis of the first parameter (UHC) and of the second parameter (CO) .

2. Method according to claim 1, comprising the step of

- calculating a first error (UHC_{ERR}) between a first reference value (UHC_{REF}) and the detected first parameter (UHC);
- calculating a second error (CO_{ERR}) between the second reference value (CO_{REF}) and the detected second parameter (CO);
- calculating the fuel flow rate (Q_{TOT}) to be supplied to the combustion chamber (4) on the basis of a first error (UHC_{ERR}) and of a second error (CO_{ERR}) .

3. Method according to claim 2, comprising the steps of:

- detecting at the exhaust (12) of the gas turbine (6) a third parameter related to the oxygen concentration (O_2);
- calculating the fuel flow rate (Q_{TOT}) to be supplied to the combustion chamber (4) on the basis of the third parameter O_2 .

4. Method according to claim 3, comprising the steps of:

- calculating a third error ($O_{2\text{ERR}}$) between a third reference value and the detected third parameter (O_2);
- calculating the fuel flow rate (Q_{TOT}) to be supplied to the combustion chamber (4) on the basis of the third

error (O_{2ERR}).

5. Method according to claim 4, comprising the step of calculating the third reference value on the basis of first parameter (UHC) and of the second parameter (CO).

6. Method according to claim 4 or 5, wherein the step of calculating the third reference value comprises calculating the third reference value on the basis of the first error (UHC_{ERR}) and of the second error (CO_{ERR}).

7. Method according to anyone of the foregoing claims, wherein the first parameter related to the unburned fuel concentration is the unburned hydrocarbon concentration (UHC) in the gas at the exhaust (12) of the gas turbine (6).

8. Method according to anyone of the foregoing claims, wherein the second parameter related to the specific energy produced by the combustion is carbon monoxide concentration (CO) in the gas at the exhaust (12) of the gas turbine (6).

9. Gas turbine plant comprising a gas turbine (6), a combustion chamber (4) fed with a mixture of fuel and oxidizer, and a control device (14, 114) for controlling the fuel supply to the gas turbine plant (1); the control device (14, 114) being configured to:

- detect at the exhaust (12) of the gas turbine (6) at least a first parameter related to the unburned fuel concentration (UHC);
- detect at the exhaust (12) of the gas turbine (6) at least a second parameter related to the specific energy produced by the combustion (CO);
- calculate a fuel flow rate (Q_{TOT}) to be supplied to the combustion chamber (4) on the basis of the first parameter (UHC) and of the second parameter (CO).

10. Plant according to claim 9, wherein the control device (14, 114) is configured to:

- calculate a first error (UHC_{ERR}) between a first reference value (UHC_{REF}) and the detected first parameter (UHC);
- calculate a second error (CO_{ERR}) between a second reference value (CO_{REF}) and the detected second parameter (CO);
- calculate the fuel flow rate (Q_{TOT}) to be supplied to the combustion chamber (4) on the basis of the first error (UHC_{ERR}) and of the second error (CO_{ERR}).

11. Plant according to claim 9 or 10, comprising a first sensor (18) configured to detect at the exhaust (12) of the gas turbine (6) a third parameter related to the oxygen concentration (O_2); the control device (14) being configured to calculate the fuel flow rate (Q_{TOT}) to be supplied to the combustion chamber (4) on the basis of the third parameter (O_2).

12. Plant according to claim 11, wherein the control device (14) is configured to:

- calculate a third error (O_{2ERR}) between a third reference value and the detected third parameter (O_2);
- calculating the fuel flow rate (Q_{TOT}) to be supplied to the combustion chamber (4) on the basis of the third error (O_{2ERR}).

13. Plant according to claim 12, wherein the control device (14) is configured to calculate the third reference value on the basis of the first parameter (UHC) and of the second parameter (CO).

14. Plant according to claim 13, wherein the control device (14) is configured to calculate the third reference value on the basis of the first parameter (UHC) and of the second parameter (CO).

15. Plant according to claim 13 or 14, wherein the control device (14) is configured to calculate the third reference value on the basis of the first error (UHC_{ERR}) and of the second error (CO_{ERR}).

FIG. 1

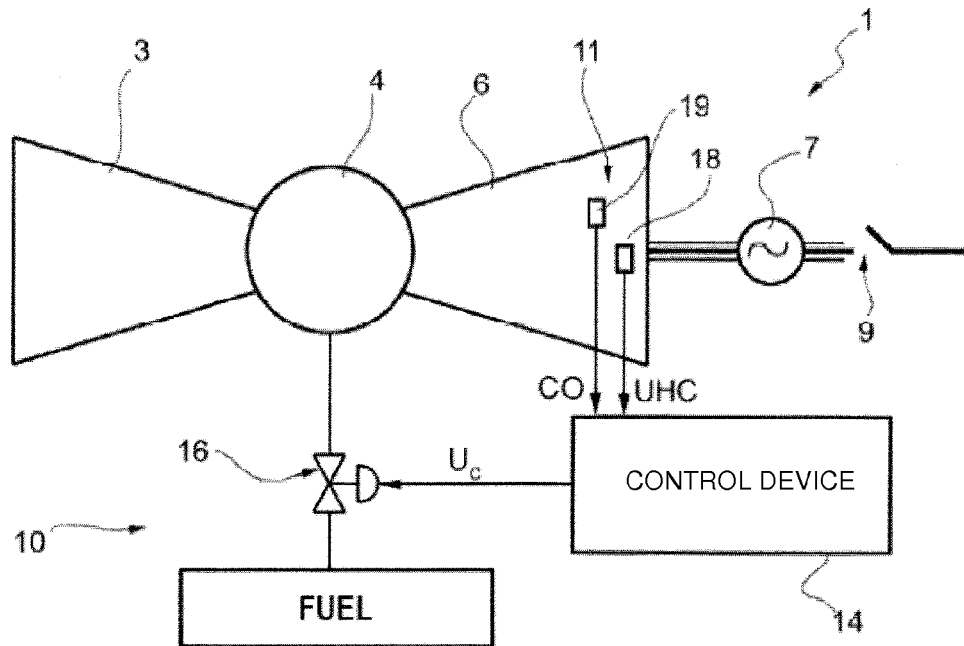


FIG. 2

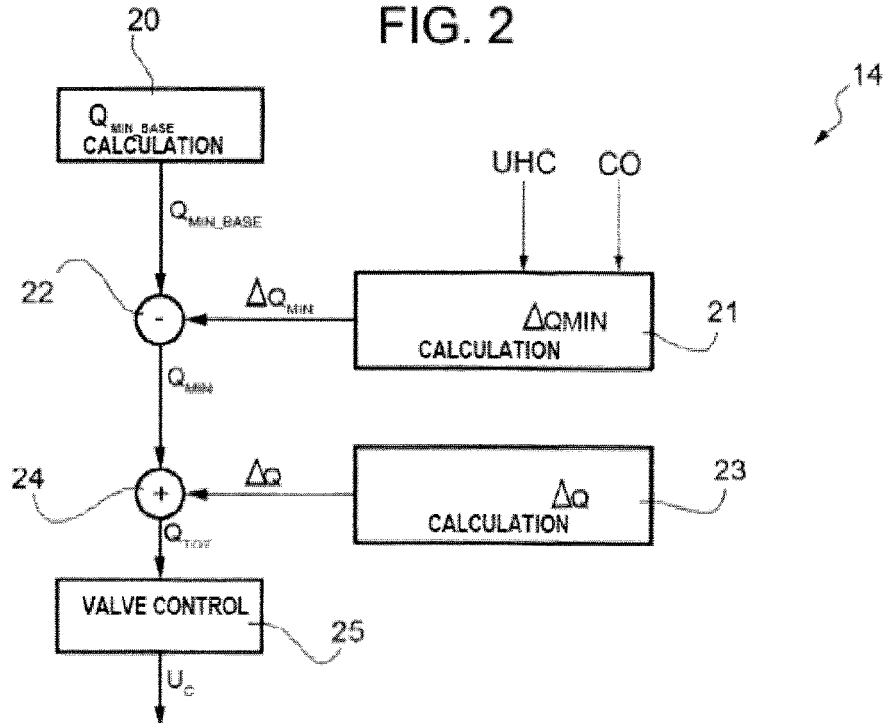


FIG. 3

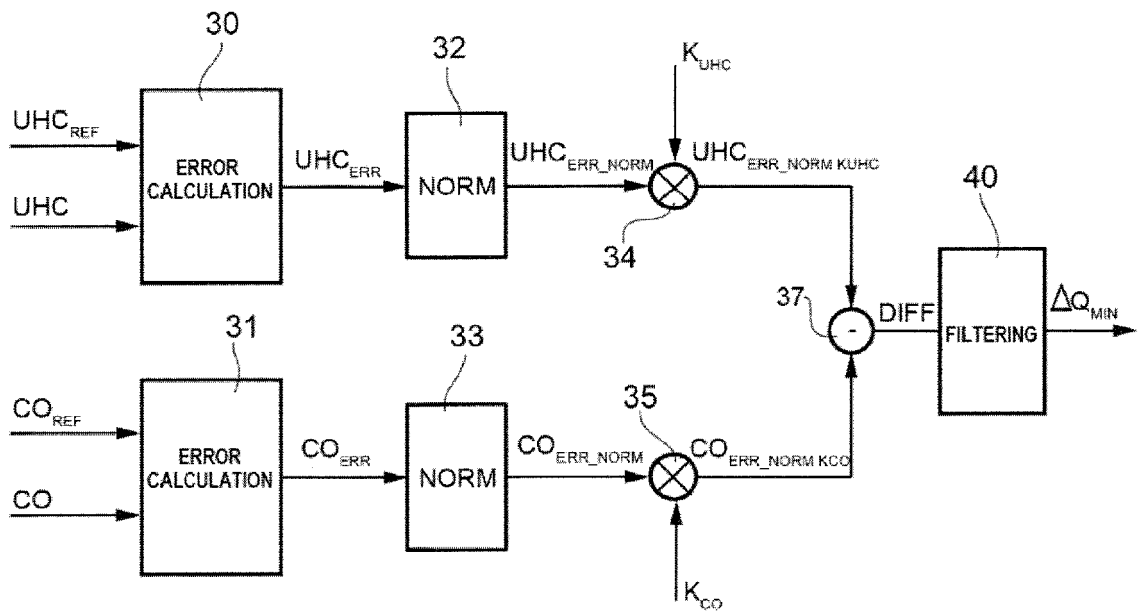


FIG. 4

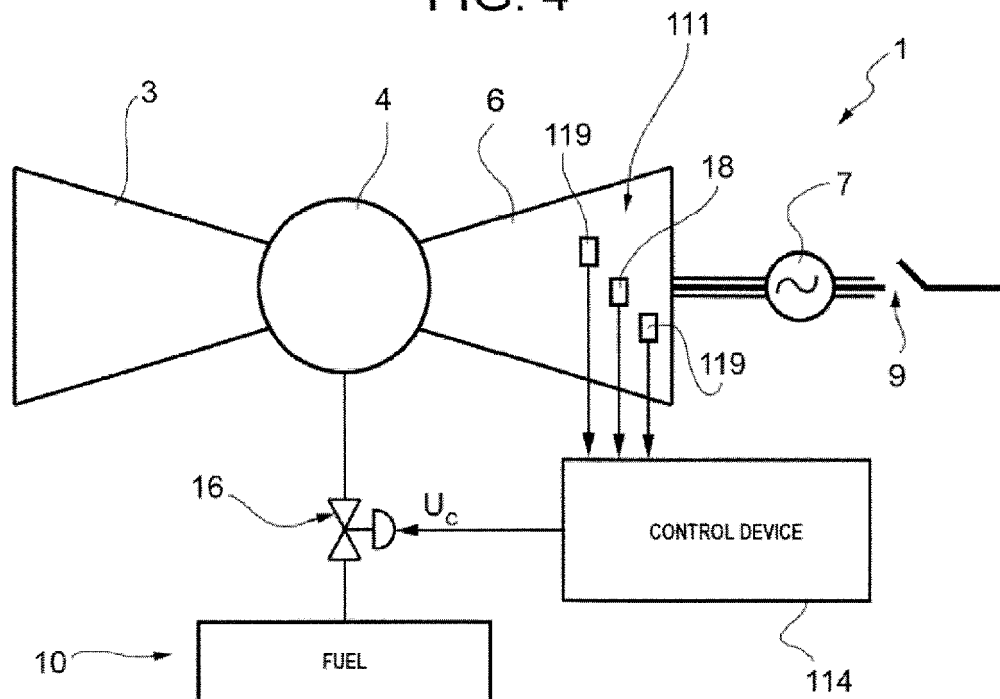


FIG. 5

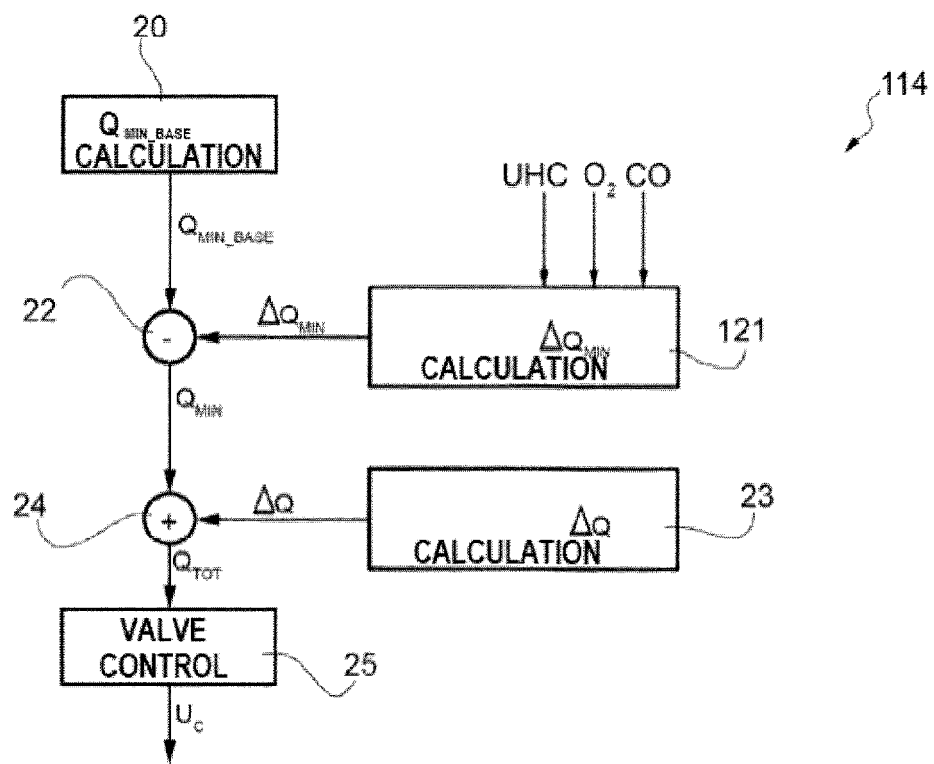


FIG. 6

