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FUEL CELL SYSTEM

Abstract

A fuel cell system includes: a plurality of fuel cell stacks; an oxidizing gas supply unit including a turbo compressor that supplies an oxidizing gas to each of the fuel cell stacks; a cooling unit that cools each of the fuel cell stacks; and a control device that determines, according to the requested output, a requested number of fuel cell stacks to be operated out of the fuel cell stacks, a target supply pressure of the oxidizing gas and a target supply flow rate of the oxidizing gas that are to be sent as a command to the oxidizing gas supply unit, and a target cooling temperature of the fuel cell stacks that is to be sent as a command to the cooling unit. The control device reduces the target cooling temperature when reducing the requested number of fuel cell stacks to be operated.

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application claims priority to Japanese Patent Application No. 2024-019613 filed on Feb. 13, 2024, incorporated herein by reference in its entirety.

BACKGROUND

1. Technical Field

[0002] The technique disclosed in the present specification relates to fuel cell systems.

2. Description of Related Art

[0003] Japanese Unexamined Patent Application Publication No. 2022-156906 (JP 2022-156906 A) describes a fuel cell system. This fuel cell system includes: a plurality of fuel cell stacks; an oxidizing gas supply unit that supplies an oxidizing gas to each of the fuel cell stacks; a cooling unit that supplies a cooling medium for cooling each of the fuel cell stacks; and a control device that determines a target supply flow rate of the oxidizing gas that is to be sent as a command to the oxidizing gas supply unit and a target supply flow rate of the cooling medium that is to be sent as a command to the cooling unit.

SUMMARY

[0004] In such a fuel cell system, the number of fuel cell stacks to be operated (that is, to generate electric power) may be reduced when the output requested from the outside is relatively low, when a failure occurs in part of the fuel cell stacks, etc. In this case, the requested output is greatly increased in those fuel cell stacks that continue to be operated.

[0005] The supply pressure and supply flow rate of the oxidizing gas to be supplied to a fuel cell stack are determined according to the output requested of the fuel cell stack (namely, the electric power to be generated by the fuel cell stack) and the temperature of the fuel cell stack. For example, when the temperature of the fuel cell stack is constant, the supply pressure and supply flow rate of the oxidizing gas need to be increased as the output requested of the fuel cell stack increases. Therefore, when reducing the number of fuel cell stacks to be operated, the supply pressure and supply flow rate of the oxidizing gas need to be increased in those fuel cell stacks that continue to be operated. In this case, if a turbo compressor is used to supply the oxidizing gas, surging may occur due to an increase in pressure ratio in the compressor. One possible way to avoid this is to reduce an increase in supply pressure of the oxidizing gas by preferentially increasing the supply flow rate of the oxidizing gas. However, the lower the supply pressure of the oxidizing gas or the higher the supply flow rate of the oxidizing gas, the more drying of an electrolytic membrane is accelerated in the fuel cell stacks, which may cause so-called drying up of the fuel cell stacks.

[0006] In view of the above circumstances, the present specification provides a technique of avoiding drying up of fuel cell stacks while avoiding surging of a turbo compressor.

[0007] As described above, when the number of fuel cell stacks to be operated is reduced, the requested power is increased in those fuel cell stacks that continue to be operated. Therefore, the supply pressure and supply flow rate of the oxidizing gas need to be increased accordingly. In this case, an increase in supply pressure of the oxidizing gas can be reduced by preferentially increasing the supply flow rate of the oxidizing gas. This reduces an increase in pressure ratio in the compressor, so that surging of the compressor can be avoided. Moreover, reducing the temperature of the fuel cell stacks reduces an increase in supply pressure of the oxidizing gas. Even when the supply flow rate of the oxidizing gas is increased accordingly, drying up of the fuel cell stacks can be reduced. That is, when reducing the number of fuel cell stacks to be operated, the temperature of

those fuel cell stacks that continue to be operated is reduced. This can avoid drying up of the fuel cell stacks while avoiding surging of the turbo compressor.
[0008] Based on the above findings, the technique disclosed in the present specification is embodied in a fuel cell system. According to a first aspect, a fuel cell system includes: [0009] a plurality of fuel cell stacks; [0010] an oxidizing gas supply unit including a turbo compressor that supplies an oxidizing gas to each of the fuel cell stacks; [0011] a cooling unit that cools each of the fuel cell stacks; and [0012] a control device that determines, according to the requested output, a requested number of fuel cell stacks to be operated out of the fuel cell stacks, a target supply pressure of the oxidizing gas and a target supply flow rate of the oxidizing gas that are to be sent as a command to the oxidizing gas supply unit, and a target cooling temperature of the fuel cell stacks that is to be sent as a command to the cooling unit.
The control device reduces the target cooling temperature when reducing the requested number of fuel cell stacks to be operated.
[0013] With the above configuration, when reducing the number of fuel cell stacks to be operated, the temperature of those fuel cell stacks that continue to be operated can be reduced. It is therefore possible to avoid drying up of the fuel cell stacks while avoiding surging of the turbo compressor.
[0014] According to a second aspect, in the first aspect, after reducing the target cooling temperature according to a reduction in the requested number of fuel cell stacks to be operated, the control device may reduce an actual number of fuel cell stacks to be operated after an actual temperature of the fuel cell stacks decreases to a predetermined value. Such a configuration can more reliably avoid drying up of the fuel cell stacks even in a case there is a time lag between when the target cooling temperature is reduced and when the actual temperature of the fuel cell stacks decreases to the predetermined value.
[0015] As described above, reducing the number of fuel cell stacks to be operated may cause surging of the turbo compressor. In order to avoid this, it is effective to reduce an increase in pressure ratio in the compressor by preferentially increasing the supply flow rate of the oxidizing gas for those fuel cell stacks that continue to be operated. However, reducing an increase in supply pressure of the oxidizing gas and increasing the supply flow rate of the oxidizing gas accordingly may cause drying up of the fuel cell stacks. Drying up of a fuel cell stack depends on the temperature of the fuel cell stack. The higher the temperature of the fuel cell stack, the more drying up of the fuel cell stack tends to occur.
[0016] It is therefore effective to prohibit or limit a decrease in number of fuel cell stacks to be operated when the temperature of the fuel cell stacks is high. Specifically, regardless of the temperature of the fuel cell stacks, the number of fuel cell stacks to be operated is reduced when the overall output requested of the fuel cell system is lower than a predetermined reference value. This reference value is not a fixed value. The higher the temperature of the fuel cell stacks, the lower the reference value is set. This reduces an increase in requested output in those fuel cell stacks that continue to be operated, and reduces an increase in supply pressure and supply flow rate required for these fuel cell stacks. It is therefore possible to avoid drying up of the fuel cell stacks while avoiding surging of the turbo compressor.
[0017] Based on the above findings, the technique disclosed in the present specification is embodied in another fuel cell system. That is, according to a third aspect, this fuel cell system includes: [0018] a plurality of fuel cell stacks; [0019] an oxidizing gas supply unit including a turbo compressor that supplies an oxidizing gas to each of the fuel cell stacks; [0020] a cooling unit that cools each of the fuel cell stacks; and a control device that determines, according to the requested output, a requested number of fuel cell stacks to be operated out of the fuel cell stacks, a target supply pressure of the oxidizing gas and a target supply flow rate of the oxidizing gas that are to be sent as a command to the oxidizing gas supply unit, and a target cooling temperature of the fuel cell stacks that is to be sent as a command to the cooling unit.
The control device decreases the requested number of fuel cell stacks to be operated when the

requested output is lower than a predetermined reference value, and sets the reference value to a lower value as an actual temperature of the fuel cell stacks increases.
[0021] With the above configuration, when reducing the number of fuel cell stacks to be operated, the higher the temperature of the fuel cell stacks, the more an increase in output requested of those fuel cell stacks that continue to be operated is reduced. That is, an increase in supply pressure and supply flow rate of the oxidizing gas that are required of the fuel cell stacks is also reduced. It is therefore possible to avoid drying up of the fuel cell stacks while avoiding surging of the turbo compressor.
[0022] According to a fourth aspect, in the third aspect, when the actual temperature of the fuel cell stacks is higher than a predetermined upper limit temperature, the control device may not reduce the requested number of fuel cell stacks to be operated, regardless of the requested output. Such a configuration can avoid a situation in which the temperature of those fuel cell stacks that continue to be operated increases excessively.
[0023] According to a fifth aspect, in the third or fourth aspect, when the actual temperature of the fuel cell stacks is lower than a predetermined lower limit temperature, the control device may not reduce the requested number of fuel cell stacks to be operated, regardless of the requested output. Such a configuration can avoid a situation in which the temperature of those fuel cell stacks that are stopped decreases excessively.

Description

BRIEF DESCRIPTION OF THE DRAWINGS
[0024] Features, advantages, and technical and industrial significance of exemplary embodiments of the disclosure will be described below with reference to the accompanying drawings, in which like signs denote like elements, and wherein:
[0025] FIG. **1** is a diagram schematically illustrating a configuration of a fuel cell system according to a first embodiment;
[0026] FIG. **2** is a diagram illustrating a relationship between a target supply pressure and target supply flow rate of an oxidizing gas;
[0027] FIG. **3** shows a surging constraint line of a compressor;
[0028] FIG. **4** is a flowchart illustrating a first process executed by the control device;
[0029] FIG. **5** shows changes over time of various parameters in the first process shown in FIG. **4**;
[0030] FIG. **6** shows a map showing the regions in which the control device permits independent operation and the regions instructing operation in the two fuel cell stacks according to the output required for the fuel cell system;
[0031] FIG. **7** is a flowchart illustrating a second process executed by the control device;
[0032] FIG. **8** shows changes over time of various parameters in the second process shown in FIG. **7**; and
[0033] FIG. **9** is a diagram schematically illustrating a configuration of a fuel cell system according to a second embodiment;
DETAILED DESCRIPTION OF EMBODIMENTS
Example 1
[0034] The fuel cell system **10** of the present embodiment will be described with reference to the drawings. The fuel cell system **10** is a power generation system that is mounted on a moving object (for example, an automobile, a bus, a truck, a train, a ship, an airplane), a stationary fuel cell device, or the like, and outputs electric power in response to an output requested from the outside.
[0035] As shown in FIG. **1**, the fuel cell system **10** includes a plurality of fuel cell stacks **12** and **14**. Each of the fuel cell stacks **12** and **14** has a structure in which a plurality of fuel cell cells are stacked. The fuel cell stacks **12** and **14** include an anode-side supply port (not shown), a cathode-

side supply port **16***a*, an anode-side discharge port (not shown), and a cathode-side discharge port **16***b*. The anode-side supply port and the cathode-side supply port **16***a* of the fuel cell stacks **12** and **14** are connected to each of the plurality of fuel cell cells in the fuel cell stacks **12** and **14**. The fuel cell stacks **12** and **14** generate electric power by chemically reacting the fuel gas taken in from the anode-side supply port and the oxidizing gas taken in from the cathode-side supply port **16***a* in the plurality of fuel cell cells. Gases (i.e., off-gas) that have passed through the plurality of fuel cell stacks **12** and **14** are discharged to the outside from the anode-side discharge port and the cathode-side discharge port **16***b*.

[0036] The plurality of fuel cell stacks **12**, **14** includes a first fuel cell stack **12** and a second fuel cell stack **14**. In the present embodiment, the first fuel cell stack **12** is electrically connected in parallel to the second fuel cell stack **14**. However, the number of the plurality of fuel cell stacks **12** and **14** is not particularly limited, and may be two or more. In the fuel cell system **10** of the present embodiment, hydrogen gas is used as the fuel gas, and air is used as the oxidizing gas. The air contains oxygen as an oxidizing agent.

[0037] As shown in FIG. **1**, the fuel cell system **10** further includes a power control unit **18**. In the present embodiment, the power control unit **18** includes a step-up converter. The power control unit **18** is electrically connected to each fuel cell stack **12**, **14**. The power control unit **18** can boost the generated power from the fuel cell stacks **12** and **14** and output the boosted power to the outside. Although not particularly limited, the power control unit **18** may further include an inverter in addition to the step-up converter.

[0038] As illustrated in FIG. **1**, the fuel cell system **10** further includes an oxidizing gas supply unit **20** and a control device **36**. The oxidizing gas supply unit **20** is a unit for supplying oxidizing gas (air) to each of the plurality of fuel cell stacks **12** and **14**. The oxidizing gas supply unit **20** includes a compressor **22**, an oxidizing gas supply path **24**, a plurality of inlet valves **26**, an off-gas discharge path **28**, a plurality of outlet valves **30**, a flow dividing path **32**, and a flow dividing valve **34**. The control device **36** can start and stop the operation of the fuel cell stacks **12**, **14**. The control device **36** may control the operation of the compressor **22**, the inlet valve **26**, the outlet valve **30**, and the flow dividing valve **34** to adjust the supply flow rate and the supply pressure of the oxidizing gas supplied to each of the fuel cell stacks **12** and **14**.

[0039] The compressor **22** is a turbo compressor. The oxidizing gas supply path **24** includes a first oxidizing gas supply path **24***a* and a second oxidizing gas supply path **24***b*. The compressor **22** is provided in the first oxidizing gas supply path **24***a*. The compressor **22** compresses air taken from the outside and supplies the compressed air to the plurality of fuel cell stacks **12** and **14**. The first oxidizing gas supply path **24***a* is connected to the cathode-side supply port **16***a* of the first fuel cell stack **12**. The second oxidizing gas supply path **24***b* is connected to the cathode-side supply port **16***a* of the second fuel cell stack **14**. The first oxidizing gas supply path **24***a* is connected to the second oxidizing gas supply path **24***b* at the branch point B**1**. A portion of the air compressed by the compressor **22** is supplied to the cathode-side supply port **16***a* of the first fuel cell stack **12** through the first oxidizing gas supply path **24***a*. The other portion of the air compressed by the compressor **22** is supplied to the cathode-side supply port **16***a* of the second fuel cell stack **14** through the second oxidizing gas supply path **24***b*. An inlet valve **26** is provided between the first oxidizing gas supply path **24***a* and the cathode-side supply port **16***a* and between the second oxidizing gas supply path **24***b* and the cathode-side supply port **16***a*, respectively. Although not particularly limited, the oxidizing gas supply unit **20** may further include an intercooler that cools the high-temperature air compressed by the compressor **22**.

[0040] The off-gas discharge path **28** includes a first off-gas discharge path **28***a* and a second off-gas discharge path **28***b*. The first off-gas discharge path **28***a* is connected to the cathode-side discharge port **16***b* of the first fuel cell stack **12**. The second off-gas discharge path **28***b* is connected to the cathode-side supply port **16***a* of the second fuel cell stack **14**. The first off-gas discharge path **28***a* is connected to the second off-gas discharge path **28***b* at the branch point B**2**.

The air that has passed through the fuel cell in the first fuel cell stack **12** is discharged from the first fuel cell stack **12** to the first off-gas discharge path **28***a* through the cathode-side discharge port **16***b*. The air that has passed through the fuel cell in the second fuel cell stack **14** is discharged from the second fuel cell stack **14** to the second off-gas discharge path **28***b* through the cathode-side discharge port **16***b*, and then sent to the first off-gas discharge path **28***a*. An outlet valve **30** is provided between the first off-gas discharge path **28***a* and the cathode-side discharge port **16***b*, and between the second off-gas discharge path **28***b* and the cathode-side discharge port **16***b*.

[0041] The flow dividing path **32** connects the oxidizing gas supply path **24** and the off-gas discharge path **28** to each other. In the present embodiment, the flow dividing path **32** connects the first oxidizing gas supply path **24***a* and the first off-gas discharge path **28***a* to each other. A flow dividing valve **34** is provided in the flow dividing path **32**. In response to the opening and closing of the flow dividing valve **34** and the outlet valve **30**, part or all of the air flowing through the first oxidizing gas supply path **24***a* is not supplied to the fuel cell stacks **12** and **14**, but is sent to the first off-gas discharge path **28***a* through the flow dividing path **32**. Accordingly, the control device **36** can adjust the supply flow rate of the oxidizing gas supplied to the fuel cell stacks **12** and **14**.

[0042] Although not shown, the fuel cell system **10** further includes a fuel gas supply unit. The fuel gas supply unit is a unit for supplying fuel gas (hydrogen gas) to the fuel cell stacks **12** and **14**.

[0043] As shown in FIG. **1**, the fuel cell system **10** further includes a cooling unit **38**. The cooling unit **38** is a unit for cooling each of the plurality of fuel cell stacks **12** and **14**. The cooling unit **38** includes a radiator **40**, a circulation path **42**, a pump **44**, and a plurality of temperature sensors **46** and **48**. The radiator **40** discharges heat from the refrigerant circulating in the circulation path **42**. The circulation path **42** includes a forward path **42***a* for supplying the refrigerant from the radiator **40** to the fuel cell stacks **12** and **14**, and a return path **42***b* for returning the refrigerant from the fuel cell stacks **12** and **14** to the radiator **40**. The pump **44** is provided in the forward path **42***a*.

[0044] The plurality of temperature sensors **46**, **48** includes a first temperature sensor **46** and a second temperature sensor **48**. The first temperature sensor **46** is provided at the outlet of the first fuel cell stack **12** in the return path **42***b*, and detects the temperature of the coolant that has passed through the first fuel cell stack **12**. The second temperature sensor **48** is provided at the outlet of the second fuel cell stack **14** in the return path **42***b*, and detects the temperature of the coolant that has passed through the second fuel cell stack **14**. The refrigerant absorbs heat from the fuel cell when passing through the plurality of fuel cell cells in the fuel cell stacks **12** and **14**. Therefore, D**1**, D**2** detected by each temperature sensor **48**, that is, the temperature of the coolant at the outlet of each fuel cell stack **12**, **14**, correlates with the actual temperature of the fuel cell stack **12**, **14**. Here, the actual temperature of the fuel cell stacks **12** and **14** means the actual temperature of the fuel cell stacks **12** and **14**. Hereinafter, the detected value D**1** by the first temperature sensor **46** is referred to as a first detected value D**1**, and the detected value D**2** by the second temperature sensor **48** is referred to as a second detected value D**2**.

[0045] The control device **36** determines the target cooling temperature TT of the fuel cell stacks **12**, **14** commanded to the cooling unit **38**. Then, the control device **36** controls the pump **44** based on D**1**, D**2** detected by the temperature sensors **46** and **48** to adjust the flow rate of the coolant supplied to the fuel cell stacks **12** and **14**. As a result, the fuel cell stacks **12** and **14** are cooled so that the temperatures of the fuel cell stacks **12** and **14** become the target cooling temperature TT. In one example, the refrigerant is water. As another embodiment, the control device **36** may directly detect the actual temperature of each of the fuel cell stacks **12** and **14**. As yet another embodiment, the control device **36** may estimate the actual temperature of each fuel cell stack **12**, **14** based on each detected value D**1**, D**2**. In other embodiments, the fuel cell system **10** may include a separate cooling unit **38** for each fuel cell stack **12**, **14**.

[0046] In the fuel cell system **10** described above, the supply pressure and the supply flow rate of the oxidizing gas to be supplied to the fuel cell stacks **12** and **14** are determined in accordance with the requested output (i.e., generated power) and the temperature of the fuel cell stacks **12** and **14**.

FIG. **2** shows the relationship between the target supply pressure and the target supply flow rate of the oxidizing gas that the control device **36** instructs the oxidizing gas supply unit **20** in accordance with the output required for the fuel cell stacks **12** and **14**. Each of the solid lines U**1** to U**4** indicates a relation between a supply flow rate of the oxidizing gas and a supply pressure of the oxidizing gas for different temperatures of the fuel cell stacks **12** and **14**. Each of the dashed lines P**1** to P**5** indicates the relation between the supply flow rate of the oxidizing gas and the supply pressure of the oxidizing gas for the different currents (i.e., generated electric power) of the fuel cell stacks **12** and **14**. The larger the number, the higher the temperature or the higher the power. For example, as shown in FIG. **2**, when the temperature of the fuel cell stacks **12** and **14** is constant, the supply pressure and the supply flow rate of the oxidizing gas are increased as the output required for the fuel cell stacks **12** and **14** is increased. Therefore, when the number of operation of the fuel cell stacks **12** and **14** is decreased, the supply pressure and the supply flow rate of the oxidizing gas also increase in the fuel cell stack **12** (or **14**) that continues the operation because the requested output increases.

[0047] In this regard, in the fuel cell system **10** of the present embodiment, a turbo compressor **22** is employed to supply the oxidizing gas. Therefore, if the pressure ratio in the compressor **22** is increased in order to increase the supply pressure of the oxidizing gas to the fuel cell stacks **12** and **14**, surging of the compressor **22** may occur. FIG. **3** shows a surging constraint line SL of the compressor **22**. Each of the dotted lines L**1** to L**5** indicates a relation between the discharge flow rate of the oxidizing gas by the compressor **22** and the pressure-ratio in the compressor **22**, with respect to a different rotational speed of the compressor **22**. Incidentally, the larger the number, which means that the rotational speed is larger. As illustrated in FIG. **3**, in the fuel cell system **10**, a surging constraint line SL is defined for an operating point (combined pressure ratio and discharge flow rate) of the compressor **22**. For example, when the operating point of the compressor **22** moves from the point C**1** to the point C**2** and exceeds the surging constraint line SL, surging may occur in the compressor **22**. In order to avoid this, in the fuel cell system **10** of the present embodiment, an increase in the supply pressure is suppressed by preferentially increasing the supply flow rate of the oxidizing gas. As a result, an increase in the pressure ratio in the compressor **22** is suppressed. Further, the discharge flow rate of the oxidizing gas by the compressor **22** is also increased, thereby effectively suppressing the generation of surging (point C**3** from the point C**1** in FIG. **3**). However, as the supply pressure of the oxidizing gas supplied to the fuel cell stack is smaller, drying of the electrolytic film is accelerated in the fuel cell stacks **12** and **14**, and so-called dry-up may occur. Alternatively, in the fuel cell stacks **12** and **14**, drying of the electrolyte membrane is accelerated as the flow rate of the oxidizing gas is increased, and so-called dry-up may occur (point F**2** from the point F**1** in FIG. **2**).

[0048] In view of the above, when the temperature of the fuel cell stacks **12** and **14** is lowered, the supply pressure of the oxidizing gas is suppressed, and even when the supply flow rate of the oxidizing gas is increased accordingly, the dry-up of the fuel cell stacks **12** and **14** can be suppressed (F**3** from the point F**1** in FIG. **2**). Based on this finding, the control device **36** of the present embodiment is configured to execute the first process illustrated in FIG. **4**. The control device **36** selectively operates one or both of the fuel cell stacks **12** and **14** by repeatedly executing the first process. In the following description, it is assumed that the number of fuel cell stacks **12**, **14** that are operated is two at first. By executing the first process, the control device **36** can reduce the temperature of the first fuel cell stack **12** that continues operation when the number of fuel cell stacks **12**, **14** that are operated is reduced to 1.

[0049] As illustrated in FIG. **4**, the control device **36** acquires a requested output from the outside (S**10**). Then, the control device **36** acquires the first detected value D**1** and the second detected value D**2** (S**12**). As described above, the first detected value D**1** and the second detected value D**2** are correlated with the actual temperatures of the fuel cell stacks **12** and **14**, respectively. In the present embodiment, the detected values D**1**, D**2** are used as indices indicating the actual temperatures of the fuel cell stacks **12**, **14**.

[0050] Next, the control device **36** calculates the requested number M of fuel cell stacks to be operated out of the fuel cell stacks **12**, **14**, based on the requested power acquired by S**10** (S**14**). When the calculated requested number M is **2** (NO in S**16**), the control device **36** sets the second temperature A**2** as the target cooling temperature TT of the fuel cell stacks **12** and **14** instructed to the cooling unit **38** (S**20**), and determines the actual number N of fuel cell stacks **12**, **14** to be operated to be 2 (S**22**). When the calculated requested number M is 1 (YES in S**16**), the control device **36** selects one fuel cell stack to continue the operation and decides to shut down the remaining fuel cell stack. In the present embodiment, the first fuel cell stack **12** is selected as the fuel cell stack that continues the operation, and it is determined to stop the operation of the second fuel cell stack **14**. However, the method of selecting the fuel cell stack to continue the operation is not particularly limited. As an example, a fuel cell stack that continues operation may be selected based on the operation history of the fuel cell stacks **12** and **14**, the actual temperature of the fuel cell stacks **12** and **14**, and the like.

[0051] The control device **36** sets the first temperature Al as the target cooling temperature TT of the first fuel cell stack **12** that continues the operation (S**18**, time R**1** in FIG. **5**). Here, the first temperature A**1** is a temperature lower than the second temperature A**2**. As described above, since the number of operations for the fuel cell stacks **12** and **14** is two at the starting point of the first process, the second temperature A**2** is set as the target cooling temperature TT of the fuel cell stacks **12** and **14**. Therefore, by S**18** process, the target cooling temperature TT of the operating first fuel cell stack **12** decreases from the second temperature A**2** to the first temperature A**1**. The first temperature A**1** and the second temperature A**2** may be fixed values or may be variable values that vary based on various parameters.

[0052] Then, the control device **36** determines whether the first detected value D**1** is equal to or less than the predetermined value AC (S**24**). Here, the predetermined value AC is a temperature that is equal to or higher than the first temperature A**1** and lower than the second temperature A**2**. The predetermined value AC may be a fixed value or may be a variable value that varies based on various parameters. The graphical A-G of FIG. **5** shows changes over time of various parameters in the first process shown in FIG. **4**. In graph B of FIG. **5**, the curve I**1** indicates the current of the first fuel cell stack **12**, and the curve I**2** indicates the current of the second fuel cell stack **14**. In the graph E of FIG. **5**, the curve OV**1** indicates the opening degree of the outlet valve **30** of the first fuel cell stack **12**, and the curve OV**2** indicates the opening degree of the outlet valve **30** of the second fuel cell stack **14**. In the graph F of FIG. **5**, the curve IV**1** indicates the opening degree of the inlet valve **26** of the first fuel cell stack **12**, and the curve IV**2** indicates the opening degree of the inlet valve **26** of the second fuel cell stack **14**. For example, as shown in the graph C of FIG. **5**, a time lag may occur after the target cooling temperature TT is lowered to the first temperature A**1** until the temperature of the first fuel cell stack **12** is lowered to a predetermined value AC. If NO in S**24**, the control device **36** determines the actual number N of fuel cell stacks **12**, **14** to be operated to **2** (S**22**). On the other hand, when S**24** is YES (time R**2** in FIG. **5**), the control device **36** determines the actual number N of fuel cell stacks **12**, **14** to be operated to be 1 (S**26**).

[0053] Thereafter, the control device **36** calculates the target supply pressure of the oxidizing gas to be instructed to the oxidizing gas supply unit **20** in accordance with the determined actual number N (S**28**), and calculates the target supply flow rate of the oxidizing gas to be instructed to the oxidizing gas supply unit **20** (S**30**). The control device **36** of the present embodiment stores in advance a map describing the relationship (see FIG. **2**) between the target supply pressure and the target supply flow rate of the oxidizing gas to be instructed to the oxidizing gas supply unit **20**. Therefore, the control device **36** calculates the target supply pressure and the target supply flow rate of the oxidizing gas according to the actual number N based on the relationship described by the map stored in advance.

[0054] The control device **36** calculates a target opening degree to be instructed to the inlet valve

26 of the oxidizing gas supply unit **20** (S**32**), and calculates a target opening degree to be instructed to the outlet valve **30** of the oxidizing gas supply unit **20** (S**32**). Note that the control device **36** may calculate a target opening degree to be instructed to the flow dividing valve **34** in addition to the outlet valve **30** of the oxidizing gas supply unit **20**. Next, the control device **36** calculates a target rotational speed to be instructed to the compressor **22** (S**36**). The control device **36** controls each unit according to the calculated value, and ends one cycle of the first process illustrated in FIG. **4**.

[0055] In the fuel cell system **10** described above, the temperature of the first fuel cell stack **12** that continues operation can be reduced when the actual number N of fuel cell stacks **12**, **14** to be operated is reduced. This makes it possible to avoid dry-up of the fuel cell stack **12** while avoiding surging of the compressor **22**.

[0056] In the first process described above, after the target cooling temperature TT is lowered according to the reduction in the requested number M, the actual number N of fuel cell stacks **12**, **14** to be operated is reduced after the actual temperature (in this case, the first detected value D**1**) of the fuel cell stacks **12** and **14** is reduced to the predetermined value AC. According to such a configuration, even when a time lag occurs after the target cooling temperature TT is lowered until the actual temperature of the fuel cell stack **12** is lowered to a predetermined value AC, it is also possible to more reliably avoid the dry-up of the fuel cell stack **12**. In the first process illustrated in FIG. **4**, the control device **36** may omit the process of S**24**. That is, in other embodiments, the control device **36** may reduce the actual number N of fuel cell stacks **12**, **14** to be operated after setting the first temperature Al as the target cooling temperature TT, regardless of the actual temperature of the fuel cell stacks **12**, **14**.

[0057] Dry-up of the fuel cell stacks **12** and **14** depends on the temperatures of the fuel cell stacks **12** and **14**, and as the temperatures of the fuel cell stacks **12** and **14** are higher, dry-up of the fuel cell stacks **12** and **14** is more likely to occur. Therefore, it is effective to prohibit or limit the decrease in the number of operations of the fuel cell stacks **12** and **14** when the temperature of the fuel cell stacks **12** and **14** is high. Specifically, regardless of the temperature of the fuel cell stacks **12**, **14**, the number of operations of the fuel cell stacks **12**, **14** is reduced when the output required for the entire fuel cell system **10** is below a predetermined reference value. However, as shown in FIG. **6**, the reference value (that is, the first upper limit output value PN and the second upper limit output value PO) for the output required for the entire fuel cell system **10** is not constant, but the reference value is set to be lower as the temperature of the fuel cell stacks **12** and **14** is higher. As a result, in the fuel cell stack **12** (or **14**) that continues operation, an increase in the requested output is suppressed, and an increase in the required supply pressure and supply flow rate is also suppressed. Based on this finding, the control device **36** of the present embodiment is configured to repeatedly execute the second process illustrated in FIG. **7**.

[0058] As illustrated in FIG. **7**, the control device **36** acquires a requested-output PR from the outside (S**40**). Then, the control device **36** acquires the first detected value D**1** and the second detected value D**2** (S**42**). As described above, since each detected value D**1**, D**2** is correlated with the actual temperature of each fuel cell stack **12**, **14**, in the present embodiment, each detected value D**1**, D**2** is adopted as an index indicating the actual temperature of each fuel cell stack **12**, **14**.

[0059] The control device **36** determines whether the two fuel cell stacks **12**, **14** are both in operation (S**44**). If S**44** is YES, the control device **36** determines whether to permit the single operation of the first fuel cell stack **12** during operation (S**46**). Specifically, the control device **36** determines whether the requested output PR is equal to or less than the second upper limit output value PO, the first detected value D**1** is equal to or less than the first lower limit temperature LN and equal to or less than the second upper limit temperature HO, and the second detected value D**2** is equal to or greater than the second lower limit temperature LO. As shown in FIG. **6**, the second upper limit output value PO is lower as the temperature of the first fuel cell stack **12** is higher. The second upper limit output value PO is a reference value with respect to a requested output PR used for determining whether or not the single operation of operating only one of the fuel cell stacks **12**

and **14** is permitted from when the two fuel cell stacks **12** and **14** are operating.
[0060] When S**44** is YES, the first fuel cell stack **12** is allowed to operate independently (S**48**). When S**44** is NO, the independent operation of the first fuel cell stack **12** is prohibited (S**48**, time R**1** in FIG. **8**). The graphical A-G of FIG. **8** shows changes over time of various parameters in the second process shown in FIG. **7**. In graph B of FIG. **8**, the curve Il indicates the current of the first fuel cell stack **12**, and the curve **12** indicates the current of the second fuel cell stack **14**. In graph C of FIG. **8**, the curve T**1** indicates the temperature of the first fuel cell stack **12**, and the curve T**2** indicates the temperature of the second fuel cell stack **14**. In the graph E of FIG. **8**, the curve OV**1** indicates the opening degree of the outlet valve **30** of the first fuel cell stack **12**, and the curve OV**2** indicates the opening degree of the outlet valve **30** of the second fuel cell stack **14**. In the graph F of FIG. **8**, the curve IV**1** indicates the opening degree of the inlet valve **26** of the first fuel cell stack **12**, and the curve IV**2** indicates the opening degree of the inlet valve **26** of the second fuel cell stack **14**.
[0061] Next, the control device **36** determines whether or not to permit the single operation of the second fuel cell stack **14** during operation (S**52**). Specifically, the control device **36** determines whether the requested output PR is equal to or less than the second upper limit output value PO, the second detected value D**2** is equal to or less than the first lower limit temperature LN and equal to or less than the second upper limit temperature HO, and the first detected value D**1** is equal to or greater than the second lower limit temperature LO. If S**52** is YES, a standalone operation is permitted for the second fuel cell stack **14** (S**54**), whereas if NO is S**52**, a standalone operation is prohibited for the second fuel cell stack **14** (S**56**).
[0062] If S**44** is NO, the control device **36** determines whether the first fuel cell stack **12** is in operation (S**60**). If S**60** is YES, the control device **36** determines whether to permit the single operation of the first fuel cell stack **12** during operation (S**62**). Specifically, the control device **36** determines whether or not the requested output PR is lower than the first upper limit output value PN, the first detected value D**1** is higher than the first lower limit temperature LN and lower than the first upper limit temperature HN, and the second detected value D**2** is higher than the first lower limit temperature LN. As shown in FIG. **6**, the first upper limit output value PN is lower as the first fuel cell stack **12** is higher. The first upper limit output value PN is a reference value for a requested output PR used to determine whether or not the two fuel cell stacks **12** and **14** should be operated in a state in which only one of the fuel cell stacks **12** and **14** is operated (that is, a state in which the fuel cell stack is operated alone).
[0063] If S**62** is YES, the single operation is permitted for the first fuel cell stack **12** (S**64**), whereas if NO is S**62**, the single operation is prohibited for the first fuel cell stack **12** (S**66**).
[0064] Next, the control device **36** determines whether or not the standalone operation is permitted for the second fuel cell stack **14** whose operation is stopped (S**68**). Specifically, the control device **36** determines whether the requested output PR is equal to or less than the second upper limit output value PO, the second detected value D**2** is equal to or less than the first lower limit temperature LN and equal to or less than the second upper limit temperature HO, and the first detected value D**1** is equal to or greater than the second lower limit temperature LO. If S**68** is YES, a standalone operation is permitted for the second fuel cell stack **14** (S**70**), whereas if NO is S**68**, a standalone operation is prohibited for the second fuel cell stack **14** (S**72**).
[0065] If S**60** is NO, the control device **36** determines whether the second fuel cell stack **14** in operation is allowed to operate alone (S**74**). Specifically, the control device **36** determines whether or not the requested output PR is lower than the first upper limit output value PN, the second detected value D**2** is higher than the first lower limit temperature LN, lower than the first upper limit temperature HN, and the first detected value D**1** is higher than the first lower limit temperature LN. If S**74** is YES, a standalone operation is permitted for the second fuel cell stack **14** (S**76**), whereas if NO is S**74**, a standalone operation is prohibited for the second fuel cell stack **14** (S**78**).

[0066] Next, the control device **36** determines whether or not the single operation is permitted for the first fuel cell stack **12** whose operation is stopped (S**80**). Specifically, the control device **36** determines whether the requested output PR is equal to or less than the second upper limit output value PO, the first detected value D**1** is equal to or less than the first lower limit temperature LN and equal to or less than the second upper limit temperature HO, and the second detected value D**2** is equal to or greater than the second lower limit temperature LO. If S**82** is YES, a standalone operation is permitted for the first fuel cell stack **12** (S**82**), whereas if S**80** is NO, a standalone operation is prohibited for the first fuel cell stack **12** (S**84**).
[0067] The control device **36** then determines the fuel cell stacks **12**, **14** to be operated (S**58**). In order to operate the determined fuel cell stacks **12** and **14**, the control device **36** controls each unit to end one cycle of the second process illustrated in FIG. **7**. In a case where the single operation is permitted for each of the fuel cell stacks **12** and **14**, the control device **36** is selected as a fuel cell stack in which one of the first fuel cell stack **12** and the second fuel cell stack **14** is operated. In this case, the method of selecting the fuel cell stack to be operated is not particularly limited. As an example, the fuel cell stacks **12** and **14** that continue to operate may be selected based on the operation history of the fuel cell stacks **12** and **14**, the actual temperature of the fuel cell stacks **12** and **14**, and the like.
[0068] In the above-described fuel cell system **10**, when the number of operation of the fuel cell stacks **12** and **14** is reduced, the higher the temperature of the fuel cell stacks **12** and **14**, the lower the increase in the output required for the fuel cell stack **12** (or **14**) that continues the operation. That is, an increase in the supply pressure and the supply flow rate of the oxidizing gas required for the fuel cell stack **12** (or **14**) is also suppressed. This makes it possible to avoid dry-up of the fuel cell stack **12** (or **14**) while avoiding surging of the compressor **22**.
[0069] Note that the first upper limit output value PN and the second upper limit output value PO in this specification are exemplary predetermined reference values with respect to the required power in the present technique. That is, in the present embodiment, two values different from each other are set to give hysteresis to the reference value. However, as another embodiment, one value may be set as the reference value without individually setting the first upper limit output value PN and the second upper limit output value PO. The same applies to the “upper limit temperature” and the “lower limit temperature” described below.
[0070] In the present embodiment, in the second process shown in FIG. **7**, the actual temperature of the fuel cell stacks **12** and **14** is also taken into consideration when determining whether or not the single operation is permitted for each of the fuel cell stacks **12** and **14**. For example, it is determined whether or not the detected-value D**1**, D**2**, which is an index indicating the actual temperature of the fuel cell stacks **12** and **14**, is lower than the first upper limit temperature HN or lower than or equal to the second upper limit temperature HO. If at least this condition is not satisfied, the single operation of the fuel cell stacks **12** and **14** is prohibited. That is, the control device **36** does not reduce the requested number M of fuel cell stacks to be operated out of the fuel cell stacks **12**, **14**, regardless of the output required for the fuel cell system **10**. According to such a configuration, it is possible to prevent a situation in which the temperature of the fuel cell stack **12** (or **14**) is excessively increased. Note that the first upper limit temperature HN and the second upper limit temperature HO in the present specification are upper limit temperatures with respect to the actual temperatures of the fuel cell stacks **12** and **14** in the present technique.
[0071] In addition to the above, in the second process illustrated in FIG. **7**, it is determined whether or not the detected value D**1**, D**2**, which is an index indicating the actual temperature of the fuel cell stacks **12** and **14**, exceeds the first lower limit temperature LN or is equal to or higher than the second lower limit temperature LO. If at least this condition is not satisfied, the single operation of the fuel cell stacks **12** and **14** is prohibited. That is, the control device **36** does not reduce the requested number M of fuel cell stacks to be operated out of the fuel cell stacks **12**, **14**, regardless of the output required for the fuel cell system **10**. According to such a configuration, it is possible

to prevent a situation in which the temperature of the fuel cell stack **12** (or **14**) is excessively lowered. The first lower limit temperature LN and the second lower limit temperature LO in the present specification are lower limit temperatures with respect to the actual temperatures of the fuel cell stacks **12** and **14** in the present technique.
[0072] In the second process illustrated in FIG. **7**, both the upper limit temperature HN, HO and the lower limit temperature LN, LO do not necessarily have to be set for the detected value D**1**, D**2**, which is an index indicating the actual temperature of the fuel cell stacks **12** and **14**. In another embodiment, either the upper limit temperature HN, HO or the lower limit temperature LN, LO may be set for the detected-value D**1**, D**2**. In still another embodiment, the upper limit temperature HN, HO and the lower limit temperature LN, LO may not be set for the detected-value D**1**, D**2**.
Example 2
[0073] The fuel cell system **110** of the second embodiment will be described with reference to FIG. **9**. As shown in FIG. **2**, in the fuel cell system **110** of the second embodiment, a plurality of fuel cell stacks **12** and **14** are electrically connected in series as compared with the fuel cell system **10** of the first embodiment. The remainder of the configuration is the same as that of the fuel cell system **10** of the first embodiment, and therefore, a repetitive description thereof will be omitted here.
[0074] As illustrated in FIG. **9**, the fuel cell system **110** further includes a first relay **50** and a second relay **52**. The first relay **50** is provided between one pole of the first fuel cell stack **12** and one pole of the power control unit **18**, and the second relay **52** is provided between the other pole of the second fuel cell stack **14** and the other pole of the power control unit **18**. As shown in FIG. **9**, when the first relay **50** and the second relay **52** are both in the first state, the first fuel cell stack **12** is electrically connected in series with the second fuel cell stack **14**. When the first relay **50** is in the first state and the second relay **52** is in the second state (the position indicated by the dotted line), the fuel cell system **10** supplies only the output from the first fuel cell stack **12** to the outside. When the second relay **52** is in the first state and the first relay **50** is in the second state (the position indicated by the dotted line), the fuel cell system **10** supplies only the output from the second fuel cell stack **14** to the outside.
[0075] Also in the above configuration, the control device **36** can repeatedly execute the first processing and the second processing in the first embodiment. Accordingly, it is possible to avoid dry-up of the fuel cell stacks **12** and **14** while avoiding surging of the compressor **22**.
[0076] While several specific examples have been described in detail above, these are merely illustrative and do not limit the scope of the claims. The technique described in **10** the claims includes various modifications and variations of the specific examples exemplified above. The technical elements described in this specification or in the drawings may be used alone or in combination to achieve technical usefulness.

Claims

1. A fuel cell system comprising: a plurality of fuel cell stacks; an oxidizing gas supply unit including a turbo compressor that supplies an oxidizing gas to each of the fuel cell stacks; a cooling unit that cools each of the fuel cell stacks; and a control device that determines, according to a requested output, a requested number of fuel cell stacks to be operated out of the fuel cell stacks, a target supply pressure of the oxidizing gas and a target supply flow rate of the oxidizing gas that are to be sent as a command to the oxidizing gas supply unit, and a target cooling temperature of the fuel cell stacks that is to be sent as a command to the cooling unit, wherein the control device reduces the target cooling temperature when reducing the requested number of fuel cell stacks to be operated.
2. The fuel cell system according to claim 1, wherein, after reducing the target cooling temperature according to a reduction in the requested number of fuel cell stacks to be operated, the control device reduces an actual number of fuel cell stacks to be operated after an actual temperature of the

fuel cell stacks decreases to a predetermined value.

3. A fuel cell system, comprising: a plurality of fuel cell stacks; an oxidizing gas supply unit including a turbo compressor that supplies an oxidizing gas to each of the fuel cell stacks; a cooling unit that cools each of the fuel cell stacks; and a control device that determines, according to a requested output, a requested number of fuel cell stacks to be operated out of the fuel cell stacks, a target supply pressure of the oxidizing gas and a target supply flow rate of the oxidizing gas that are to be sent as a command to the oxidizing gas supply unit, and a target cooling temperature of the fuel cell stacks that is to be sent as a command to the cooling unit, wherein the control device decreases the requested number of fuel cell stacks to be operated when the requested output is lower than a predetermined reference value, and sets the reference value to a lower value as an actual temperature of the fuel cell stacks increases.

4. The fuel cell system according to claim 3, wherein, when the actual temperature of the fuel cell stacks is higher than a predetermined upper limit temperature, the control device does not reduce the requested number of fuel cell stacks to be operated, regardless of the requested output.

5. The fuel cell system according to claim 3, wherein, when the actual temperature of the fuel cell stacks is lower than a predetermined lower limit temperature, the control device does not reduce the requested number of fuel cell stacks to be operated, regardless of the requested output.