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(54) **HYDROGEN PRODUCTION SYSTEM AND HYDROGEN PRODUCTION METHOD**

(57) In a hydrogen production system that produces hydrogen using a plurality of water electrolysis stacks, a technique is provided, which is capable of effectively restraining a degradation of the water electrolysis stacks. In the hydrogen production system according to the present disclosure, any one of an operation priority stack, a stop priority stack, and an intermediate operation stack is allocated as the operation states of the water electrolysis stacks.

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Description

BACKGROUND OF THE INVENTION

1. Field of the Invention

[0001] The present disclosure relates to a hydrogen production system that produces hydrogen by a plurality of water electrolysis stacks.

2. Description of Related Art

[0002] In order to promote the use of hydrogen energy, it is required to reduce the hydrogen price. In order to reduce the hydrogen price, it is necessary to reduce the cost required for hydrogen production. For example, hydrogen is produced by a method such as electrolysis of water and the like (hereinafter referred to as water electrolysis). The cost for hydrogen production is roughly classified into capital expense (CAPEX) and operating expense (OPEX). The OPEX includes the procurement cost of power used for water electrolysis, the system maintenance cost, and the like. In order to reduce the CAPEX, the following efforts are required.

- Decrease in equipment price
- Improvement of equipment operation rate (increase in amount of hydrogen produced)
- Improvement of service life of equipment (decrease in depreciation cost of equipment)

[0003] The hydrogen production utilizing renewable energy has recently attracted growing attentions, but since the amount of power generation by the renewable energy varies due to the influence of wind power and weather, it is challenging to improve the operation rate of hydrogen production equipment. As a way to deal with this, producing hydrogen by leveling the power by use of storage batteries is suggested, but the use of the storage batteries will result in increased equipment price, making it difficult to reduce CAPEX. Therefore, a technique capable of reducing CAPEX without using the storage battery is required.

[0004] In order to improve the service life of the hydrogen production system, it is necessary to restrain the degradation of its component, that is, the water electrolysis cells. Examples of the water electrolysis method include alkaline electrolysis, proton exchange membrane (PEM) electrolysis, anion exchange membrane (AEM) electrolysis, and the like. It will be described below how the degradation of the PEM electrolytic cell is restrained.

[0005] According to non-patent literature 1 C. Rakousky et al., J. Power Sources 342, 38 (2017) (Non-PTL 1), the degradation of the water electrolysis cell has the following characteristics:

(a) when the operation at high power is continued for a long time (about 1000 hours), the degradation rate is very high (that is, the intermittent operation in which the output is lowered in the middle is desirable);

(b) in the intermittent operation, degradation can be restrained by transitioning between high power and zero power rather than transitioning between high power and intermediate power;

(c) in the intermittent operation, shortening the period of the output cycle (frequently switching ON and OFF) results in early degradation.

[0006] There are many techniques for forming a megawatt-class hydrogen production system using a plurality of water electrolysis stacks. In addition, JP-A-2020-084259 (PTL 1) describes a technique for individually controlling ON and OFF of the water electrolysis stacks. For example, according to the power variation of renewable energy, the number of operating stacks is increased when the power is large. Further, PTL 1 discloses a technique for selecting a stack to be operated while monitoring the degradation state of the stack in order to prevent shortening of the life due to overuse of the stack.

[0007] Two types of power, system power and renewable energy power, are considered as the power to be input to the water electrolysis system. When the water electrolysis system is operated at the constant rating using system power, there can be early degradation for the reason (a) described above. Meanwhile, renewable energy power is generated intermittently according to the influence of wind or weather, and it is likely that its output is generated in a medium amount that is smaller than the rating (maximum power) without being dropped to zero. When such power is applied to the water electrolysis system, since the output frequently transitions between the high power and the intermediate power, there can be degradation for the reasons (b) and (c) described above.

[0008] When inputting renewable energy power to the water electrolysis system, it is conceivable to individually switch ON and OFF the water electrolysis stacks as in PTL 1. Switching ON and OFF the water electrolysis stacks according to a short-term variation of the renewable energy power is not always useful as there is a possibility that the water electrolysis stack may not be responsive enough. Further, since there is an issue of decreased operation rate of the water electrolysis stack when the renewable energy power is used, the operation rate may sometimes be increased by limiting the upper limit output of the water electrolysis stack. In such a case, since the operation rate of the water electrolysis stacks increases as a whole, the number of the water electrolysis stacks that can be switched OFF decreases, and as a result, restraining the degradation by the ON and OFF control cannot be sufficiently implemented.

SUMMARY OF THE INVENTION

[0009] The present disclosure has been made in view of the problems described above, and an object of the present disclosure is to provide, in a hydrogen production system that produces hydrogen using a plurality of water electrolysis stacks, a technique capable of effectively restraining a degradation of the water electrolysis stacks.

[0010] In the hydrogen production system according to the present disclosure, any one of an operation priority stack, a stop priority stack, and an intermediate operation stack is allocated as the operation states of the water electrolysis stacks.

[0011] According to the hydrogen production system according to the present disclosure, degradation of the water electrolysis stacks can be effectively restrained.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012]

FIG. 1 is a block diagram of a hydrogen production system 1 according to a first embodiment;
FIG. 2 illustrates an example of a change with time of an amount of power generation by renewable energy;
FIG. 3 illustrates an example of an operation rotation formulated by an operation plan formulation unit according to an embodiment;
FIG. 4A illustrates a change with time of a power supplied to each water electrolysis stack when each water electrolysis stack is operated according to the operation rotation plan of FIG. 3;
FIG. 4B illustrates a change with time of the power supplied to each water electrolysis stack when each water electrolysis stack is operated according to the operation rotation plan of FIG. 3;
FIG. 4C illustrates a change with time of the power supplied to each water electrolysis stack when each water electrolysis stack is operated according to the operation rotation plan of FIG. 3;
FIG. 5 illustrates a table illustrating the results of testing the degradation rates of the water electrolysis stacks;
FIG. 6 illustrates an example of an operation rotation plan when six water electrolysis stacks are operated;
FIG. 7A illustrates a change with time of the power supplied to each water electrolysis stack when each water electrolysis stack is operated according to the operation rotation plan of FIG. 6;
FIG. 7B illustrates a change with time of the power supplied to each water electrolysis stack when each water electrolysis stack is operated according to the operation rotation plan of FIG. 6;
FIG. 7C illustrates a change with time of the power supplied to each water electrolysis stack when each water electrolysis stack is operated according to the operation rotation plan of FIG. 6;
FIG. 8 illustrates an example of a change with time of an amount of power generation by photovoltaic power generation;
FIG. 9 illustrates a change with time of the power distributed to the operation stacks when the supplied power in FIG. 8 is distributed to the water electrolysis stacks according to the related procedure;
FIG. 10 illustrates an example of an operation rotation plan when the power supply varies as illustrated in FIG. 8;
FIG. 11A illustrates a change with time of the power supplied to each water electrolysis stack when each water electrolysis stack is operated according to the operation rotation plan of FIG. 10;
FIG. 11B illustrates a change with time of the power supplied to each water electrolysis stack when each water electrolysis stack is operated according to the operation rotation plan of FIG. 10;
FIG. 11C illustrates a change with time of the power supplied to each water electrolysis stack when each water electrolysis stack is operated according to the operation rotation plan of FIG. 10;
FIG. 12 is a block diagram of a hydrogen production system according to a second embodiment;
FIG. 13 is a block diagram of a hydrogen production system according to a third embodiment;
FIG. 14 is a block diagram of a hydrogen production system according to a fourth embodiment;
FIG. 15 is a block diagram of a hydrogen production system 1 according to a fifth embodiment;
FIG. 16A illustrates the operation rotation when the operation state of each water electrolysis stack is allocated according to the related procedure in the fifth embodiment; and
FIG. 16B illustrates the operation rotation of the hydrogen production system according to the fifth embodiment.

DESCRIPTION OF EMBODIMENTS

(Embodiment 1)

[0013] FIG. 1 is a block diagram of a hydrogen production system 1 according to a first embodiment of the present disclosure. The hydrogen production system 1 is a system that produces hydrogen using renewable energy or alternating current (AC) power supplied by a power transmission and distribution system. The hydrogen production system 1 produces hydrogen by operating water electrolysis stacks 11 using the supplied power. The hydrogen production system 1 includes the water electrolysis stacks 11, DC/DC converters 12, an AC/DC rectifier 13, and a power distribution control system 14.

[0014] The water electrolysis stacks 11 produce hydrogen by electrolyzing water. In FIG. 1, three pairs of water electrolysis stacks 11 are connected in parallel, in which each pair includes two water electrolysis stacks 11, in which the two water electrolysis stacks 11 are connected in series. The hydrogen produced by the water electrolysis stacks 11 is output to transportation equipment and storage equipment.

[0015] The AC/DC rectifier 13 converts the AC power supplied to the hydrogen production system 1 into direct current (DC) power and outputs the converted power to the DC/DC converters 12. The DC/DC converters 12 supply power to the water electrolysis stacks 11 to control the operation states of the water electrolysis stacks 11.

[0016] The power distribution control system 14 outputs an operation command to the DC/DC converters 12 to control the operation states of the water electrolysis stacks 11 via the DC/DC converters 12. The power distribution control system 14 includes an operation plan formulation unit 141, a stack operation allocation unit 142, a power distribution command unit 143, a degradation characteristic data management unit 144, and a degradation rate estimation unit 145.

[0017] The operation plan formulation unit 141 formulates an operation rotation plan for the water electrolysis stacks 11. The operation rotation as used herein is an order of allocating one of an operation priority stack, a stop priority stack, and an intermediate operation stack, which will be described below, as the operation state of each water electrolysis stack 11. The stack operation allocation unit 142 determines the operation state of each water electrolysis stack 11 according to the operation rotation plan formulated by the operation plan formulation unit 141. The power distribution command unit 143 gives current command values to the DC/DC converters 12 such that the water electrolysis stacks 11 operate according to their operation states.

[0018] The degradation characteristic data management unit 144 holds degradation characteristic data describing the degradation characteristics of the water electrolysis stacks 11. The operation plan formulation unit 141 can formulate an operation rotation plan according to these degradation characteristics. The degradation rate estimation unit 145 estimates the degradation rate of each water electrolysis stack 11 when assuming that the water electrolysis stack 11 is operated according to the plan.

[0019] FIG. 2 illustrates an example of a change with time of the amount of power generation by renewable energy. In this example, the amount of power generation by wind power generation is illustrated. In the related operation controlling, the upper limit output of the water electrolysis stacks may sometimes be limited as illustrated in FIG. 2 in order to increase the operation rate of the water electrolysis stacks. This improves the operation rate, but on the other hand reduces the number of water electrolysis stacks that can be stopped. For example, when the power such as that illustrated in FIG. 2 is evenly supplied to eight water electrolysis stacks, the operation rate of the water electrolysis stacks is 84.8%.

[0020] FIG. 3 illustrates an example of the operation rotation formulated by the operation plan formulation unit 141 according to the present embodiment. In this example, an example is illustrated, in which each pair of two of eight water electrolysis stacks 11 is allocated with the operation state. The operation plan formulation unit 141 allocates one of (a) operation priority stack, (b) stop priority stack, and (c) intermediate operation stack as the operation state of the water electrolysis stack 11. In FIG. 3, an example is illustrated, in which the operation states are allocated in the order of operation priority => stop priority => intermediate operation => intermediate operation, and the operation states are rotated so as not to overlap, except for the intermediate operation stack.

[0021] The operation priority stack is a stack to which power is preferentially distributed as compared with other water electrolysis stacks 11. The stop priority stack is a stack for which the power supply is preferentially stopped as compared with the other water electrolysis stacks 11. The intermediate operation stack is a stack that receives the power supply intermediately between those described above. For example, all the power received by the hydrogen production system 1 is first allocated to the operation priority stack and the stop priority stack, and then when there is remaining power, it is allocated to the intermediate operation stack.

[0022] FIGS. 4A to 4C illustrate a change with time of the power supplied to each water electrolysis stack 11 when each water electrolysis stack 11 is operated according to the operation rotation plan of FIG. 3. The operation priority stack has the highest priority to be distributed with the power, and the stop priority stack has the highest priority to not be distributed with the power. The intermediate operation stack receives the power supply intermediately between them.

[0023] FIG. 5 illustrates a table illustrating the results of testing the degradation rates of the water electrolysis stacks. These are described in Non-PTL 1, and illustrate the results of testing the degradation rate (voltage rise rate) in each of five modes. First, the characteristics of the water electrolysis stack that can be seen from these test results will be described, and then the estimation results of when the same test is performed according to the present embodiment will be illustrated. However, since the present embodiment uses the water electrolysis stacks and Non-PTL 1 uses a single water electrolysis cell, note that the absolute values of the numbers are different from each other.

[0024] When the current density of 2 A/cm^2 is maintained as in mode B, the degradation rate is 194 $\mu V/h$, which is the highest. Therefore, it can be seen that when the operation at high power is continued for a long time (about 1000 hours), the degradation rate is very high (that is, the intermittent operation in which the output is lowered in the middle is desirable).

[0025] When the current density is transitioned between 2 A/cm^2 and 1 A/cm^2 as in mode C, the degradation rate is 65 $\mu V/h$, when the current density is transitioned between 2 A/cm^2 and 0 A/cm^2 as in mode D, the degradation rate is 16 $\mu V/h$. Therefore, it can be seen that, during the intermittent operation, degradation can be restrained by transitioning between high power and zero power rather than transitioning between high power and intermediate power.

[0026] In mode E, the output of 2 A/cm^2 is continued for 10 minutes, and then the output of 0 A/cm^2 is continued for 10 minutes. Therefore, the output cycle is extremely short compared to the other modes (for example, modes C and D have a cycle of 6 hours + 6 hours). The degradation rate of mode E is 50 μV/h, and the degradation rate of mode D is 16 μV/h. Therefore, it can be seen that the shorter the output cycle, the faster the degradation.

[0027] When the operation procedure of evenly distributing the power to each water electrolysis stack as in the related example is used, since the water electrolysis stacks transition between the high power and the intermediate power, the operation corresponding to the mode C is performed. Then, when the stacks are frequently switched ON and OFF as in PTL 1, the operation corresponding to mode E is performed. Then, in the related operation procedure, in addition to the degradation rate of mode C (65 μV/h), it is estimated that, by shortening the mode cycle from 6 h to 10 min, a degradation rate corresponding to a difference (50 - 16 = 34 μV/h) between modes D and E is added. That is, the degradation rate in the related operation procedure is estimated to be about 99 μV/h.

[0028] Since the operation priority stack according to the present embodiment corresponds to mode D in that the stop priority stack is allocated after the operation at high power, the resulting degradation is 16 μV/h continuously for 6 hours. Since the stop priority stack according to the present embodiment frequently transitions between the high power and the zero power, this corresponds to the mode E, and the resulting degradation is 50 μV/h continuously for 6 hours. Since the intermediate operation stack according to the present embodiment frequently switches ON and OFF in addition to transitioning between the high power and the intermediate power, the degradation rate is 99 μV/h as described above, which continues for 6 h × 2. Therefore, the degradation rate in this embodiment is 66 μV/h on average for each operation mode, and the degradation rate can be reduced by 33% as compared with the related example.

[0029] FIG. 6 illustrates an example of an operation rotation plan when six water electrolysis stacks 11 are operated. The operation state is allocated to each stack pair in the order of operation priority => stop priority => intermediate operation such that the operation states do not overlap among the pairs.

[0030] FIGS. 7A to 7C illustrate a change with time of the power supplied to each water electrolysis stack 11 when each water electrolysis stack 11 is operated according to the operation rotation plan of FIG. 6. When the degradation rate is estimated in the same manner as in the example of FIGS. 3 to 4C (first example), the degradation rate is 55 μV/h, and the degradation rate can be reduced by 44% as compared with the related example. It is considered that the degradation restraining effect is greater in this example (second example) than in the first example because the ratio of the number of operation priority stacks and stop priority stacks having a relatively low degradation rate is increased.

[0031] However, when comparing the operation rates of the first example and the second example, in the second example, the operation rate of the operation priority stack is decreased (comparison between FIGS. 4A and 7A), and the operation rate of the stop priority stack is increased (comparison of FIGS. 4B and 7B). As a result, for example, there is a possibility that the accuracy of approximation that regards the degradation rate of the operation priority stack as corresponding to mode D is decreased. That is, even for the same operation priority stack, there is a possibility that the degradation rate of the second example is higher than that of the first example. Therefore, it is effective to formulate the operation rotation while pre-evaluating the degradation rate for each input power data or acquiring the same during operation.

[0032] Specifically, for example, the degradation rate estimation unit 145 may estimate the degradation rate of each water electrolysis stack 11 under the current operation rotation plan, and the operation plan formulation unit 141 may formulate a rotation plan such that the difference in the degradation rate between the water electrolysis stacks 11 is as small as possible. It is not always necessary to make the degradation rates of the water electrolysis stacks 11 exactly equal, and as long as at least the difference in the degradation rates between the stacks is reduced, the corresponding effect can be exhibited.

[0033] FIG. 8 illustrates an example of a change with time of the amount of power generation by photovoltaic power generation. It can be seen that the amount of power generation varies according to the time of day, and that the amount of power generation decreases due to the influence of clouds. An example in which this power is supplied to the hydrogen production system 1 will be considered below.

[0034] FIG. 9 illustrates a change with time of the power distributed to the operation stacks when the supplied power in FIG. 8 is distributed to the water electrolysis stacks according to the related procedure. When the amount of power generation changes greatly according to the time of day as in photovoltaic power generation, since the output is filtered with reference to the upper limit as illustrated in FIG. 2, it is difficult to increase the operation rate of the water electrolysis system. Therefore, first, as an example of the related controlling, as disclosed in PTL 1, the result of power distribution when the water electrolysis stacks are switched ON and OFF according to the time zone (amount of power generation) is estimated. In this example, the power is evenly distributed to the eight water electrolysis stacks. FIG. 9 shows the result.

[0035] The average operation rate of the operation stacks illustrated in FIG. 9 is as low as 58.1%, and since frequent transitions between high power and intermediate power are observed, there can be early degradation. Therefore, it can be seen that it is difficult to restrain the degradation of the water electrolysis stacks by the related method of controlling the number of stacks to be switched ON and OFF.

[0036] FIG. 10 illustrates an example of an operation rotation plan when the power supply varies as illustrated in FIG. 8. During the period when the power supplied to the hydrogen production system 1 is less than the threshold value, instead of the operation rotation described in FIGS. 3 and 6, the operation plan formulation unit 141 allocates the water electrolysis stack 11 that is completely switched OFF (cut off from power supply). This is called the stop stack. For example, in FIG. 10, in the period of 0 to 2 h during which the supplied power is small, only four water electrolysis stacks 11 are operated, and in the period of 8 to 10 h during which the supplied power is further decreased, only two stacks are operated.

[0037] Regarding which water electrolysis stack 11 is to be switched OFF, it may be done in a manner in which the operation rate of each water electrolysis stack 11 is kept as uniform as possible, for example. It is preferable that the average operation rate is kept as uniform as possible over a certain period of time, but it is not always necessary to make the operation rate strictly uniform at all times. Further, it is not always necessary to allocate the stop stack over the entire period when the supplied power is low, and if the stop stack is allocated for at least a portion of the low power period, the degradation restraining effect to that extent can be exhibited.

[0038] FIGS. 11A to 11C illustrate a change with time of the power supplied to each water electrolysis stack 11 when each water electrolysis stack 11 is operated according to the operation rotation plan of FIG. 10. Since the operation priority stack has an improved operation rate and a reduced frequency of transitions between high power and intermediate power as compared with FIG. 9, it is expected that the degradation rate will be lower than that of the related controlling.

[0039] In the estimation of the related controlling method of FIG. 9, the number of water electrolysis stacks to be switched ON and OFF is changed in real time (in seconds) according to the variation of the input power. On the other hand, according to the operation rotation of FIG. 10, since the operation states of the water electrolysis stacks 11 can be controlled by the 'current distribution control by the DC/DC converter 12' in addition to 'ON and OFF controlling every 2 hours', there is also an advantage in terms of following capability with respect to variations.

[0040] From the above, even when the renewable energy that varies according to the time zone is supplied as in photovoltaic power generation, degradation of the water electrolysis stacks 11 can be restrained by using the controlling method of the present embodiment.

(Embodiment 1 - Summary)

[0041] The hydrogen production system 1 according to the first embodiment allocates the operation states of the water electrolysis stacks 11 in the order of operation priority stack => stop priority stack => intermediate operation stack. As a result, degradation of the water electrolysis stacks 11 can be restrained as compared with the related operation controlling that equalizes the operation rate of the water electrolysis stack 11 and operation controlling that frequently repeats ON and OFF.

[0042] During a period when the supplied power is small, the hydrogen production system 1 according to the first embodiment additionally allocates the stop stack as the operation state of the water electrolysis stacks 11, in addition to that described above. As a result, even when a power supply that greatly varies with time is received as in the case of photovoltaic power generation, degradation of the water electrolysis stacks 11 can be effectively restrained.

(Embodiment 2)

[0043] FIG. 12 is a block diagram of a hydrogen production system 1 according to a second embodiment of the present disclosure. In the second embodiment, in addition to the configuration described in the first embodiment, a power generation amount prediction unit 21 is provided. The power generation amount prediction unit 21 may be configured as a part of the hydrogen production system 1 or may be configured as a functional unit separate from the hydrogen production system 1.

[0044] The power generation amount prediction unit 21 predicts the amount of power generation of renewable energy according to a known method. For example, the following may be considered: (a) prediction using meteorological data 22 (data describing meteorological conditions such as weather, wind conditions, and the like); (b) data acquisition on amount of power generation from renewable energy power generation facilities in real time; and (c) a combination of these, and the like.

[0045] The power distribution control system 14 receives the predicted amount of power generation from the power generation amount prediction unit 21, and accordingly allocates the operation state of each water electrolysis stack 11. For example, when the amount of power generation is large, the number of operation priority stacks is increased. This is because there is a concern that, when the amount of power generation is increased while maintaining the number of stacks as is, the power distributed to the stop priority stack is increased and the transition between the high power and the intermediate power is increased, which will result in accelerated degradation. Further, as in the case of the photovoltaic power generation of the first embodiment, when the amount of power generation is expected to decrease according to the time zone, ON and OFF of the water electrolysis stacks 11 may be controlled as illustrated in FIG. 10. With these controlling, degradation of the water electrolysis stacks 11 can be restrained while following variations in the amount of renewable energy power generation.

(Embodiment 3)

[0046] FIG. 13 is a block diagram of a hydrogen production system 1 according to a third embodiment of the present disclosure. In the third embodiment, in addition to the configuration described in the first embodiment, a degradation monitoring unit 3 is provided. The degradation monitoring unit 3 may be configured as a part of the hydrogen production system 1 or may be configured as a functional unit separate from the hydrogen production system 1.

[0047] For example, the degradation monitoring unit 3 receives an output current and an output voltage of the water electrolysis stacks 11 from the power distribution control system 14, and uses the same to calculate the state of health (SOH) of the water electrolysis stacks 11. The power distribution control system 14 allocates the operation state of each water electrolysis stack 11 according to the state of health thereof.

[0048] For example, the power distribution control system 14 allocates the operation state such that, for the water electrolysis stack 11 having a reduced SOH, the number of times to perform an operation with a larger degradation rate as compared with the other water electrolysis stacks 11 (for example, the number of times to allocate the intermediate operation stack) is reduced. As a result, it is possible to avoid a situation in which only a specific stack is degraded at an early stage and needs to be replaced, so that the maintenance cost associated with the replacement can be reduced.

(Embodiment 4)

[0049] FIG. 14 is a block diagram of a hydrogen production system 1 according to a fourth embodiment of the present disclosure. In the fourth embodiment, in addition to the configuration described in the first embodiment, a management system 41 and a distributor 42 are provided. The management system 41 and the distributor 42 may be configured as parts of the hydrogen production system 1 or may be configured as functional units separate from the hydrogen production system 1.

[0050] According to the present embodiment, the distributor 42 switches between supplying the power generated by a renewable energy power generation facility 43 to the water electrolysis stacks 11 and selling the power to a consumer 44 (that is, outputting the received power to the power transmission and distribution system), according to instruction from the management system 41. For example, the management system 41 instructs the distributor 42 on a distribution ratio between the two options.

[0051] The management system 41 further collects demand data for various energies (for example, power, heat, hydrogen, and the like) from the consumer 44, and controls the energy distribution according to the data. For example, it is possible to carry out controlling, such as predicting the power demand and a spot price of energy that reflects the same, increasing a power selling ratio when the power demand is large, producing hydrogen when the power demand is low, and the like. Data for the supply amount of these energies may also be collected, and the controlling described above may be performed according to the balance between supply and demand.

[0052] When the amount of power supplied to the hydrogen production system 1 is large, the number of stacks that can be allocated as the stop priority stack is decreased relatively. In such a case, the distributor 42 may increase the ratio of selling power to the consumer 44 (in other words, when the amount of power generation is decreased, the ratio of selling power is decreased accordingly). As a result, since the power supplied to the water electrolysis stack 11 is reduced, the number of stacks that can be allocated as the stop priority stack is increased. As a result, degradation of the water electrolysis stacks 11 can be restrained.

(Embodiment 5)

[0053] FIG. 15 is a block diagram of a hydrogen production system 1 according to a fifth embodiment of the present disclosure. In the fifth embodiment, the hydrogen production system 1 receives power from a power transmission and distribution system 5. Therefore, unlike the case of receiving renewable energy power, a constant current load is applied to the water electrolysis stacks 11, and accordingly, it is necessary to consider the degradation for this. Other configurations are the same as those of the first to fourth embodiments.

[0054] FIG. 16A illustrates the operation rotation when the operation state of each water electrolysis stack is allocated according to the related procedure. The numerical values are the current densities (A/cm^2) supplied to the water electrolysis stacks. The power is evenly distributed to each stack.

[0055] FIG. 16B illustrates the operation rotation of the hydrogen production system 1 according to the present embodiment. Assuming that the rated current is 2.0 A/cm^2, the stack with the current value of 1.8 A/cm^2 roughly corresponds to the operation priority stack, and the stack with the current value of 1.0 A/cm^2 roughly corresponds to the stop priority stack. Therefore, by allocating these as the operation states of the stacks of FIG. 16B, the same effect as that of the first embodiment can be exhibited. Alternatively, in consideration of the fact that the variation with time of the power supplied by the power transmission and distribution system 5 is small, rather than increasing or decreasing the power supplied to the water electrolysis stacks 11 like the operation priority stack and the stop priority stack, the current values illustrated in FIG. 16B may be fixed and supplied to the water electrolysis stack 11 as they are. Regarding which one is to be used, it may be switched according to the type of power supplied.

[0056] The degradation rate in the related controlling of FIG. 16A is estimated to be 78 μV/h by linearly interpolating the degradation rate in mode B of FIG. 5. The degradation rate in FIG. 16B is estimated to be 52 μV/h by linearly interpolating the degradation rate in mode C. Therefore, the degradation rate can be reduced by 33% as compared with the related controlling. Therefore, even when receiving a power that varies little with time, such as a system power, degradation of the water electrolysis stacks 11 can be restrained.

<Modified Examples of Present Disclosure>

[0057] The present disclosure is not limited to the embodiments described above, and includes various modified examples. For example, the embodiments described above are described in detail in order to explain the present disclosure in an easy-to-understand manner, and are not necessarily limited to those having all the configurations described above. Further, a part of the configuration of an embodiment can be replaced with the configuration of another embodiment, and the configuration of another embodiment can be added to the configuration of an embodiment. In addition, it is possible to add, delete, and replace other configurations for a part of the configuration of each embodiment.

[0058] In the degradation test of Non-PTL 1, it is described that a voltage of 1.4 V or more is applied to the water electrolysis cell even when the current density is zero. This is slightly higher than the theoretical voltage (1.23 V) for electrolysis of water, and is a voltage value near the start of the electrolytic reaction. If the voltage is lowered to 0 V during operation, a reverse current will flow, which may degrade the water electrolysis cell. Therefore, according to the present disclosure, even when the current flowing through the water electrolysis stacks 11 is zero, the DC/DC converters 12 are arranged at the inlets of the paths where power is supplied to the water electrolysis stacks 11 such that a voltage near the start of the electrolysis reaction can be applied to the water electrolysis stacks 11. A role similar to that described above can be replaced by a power converter capable of at least two or more voltage outputs. Therefore, such a power converter may be arranged instead of the DC/DC converter 12.

[0059] The present disclosure can also be applied to a fuel cell operating with the reverse reaction of water electrolysis. In that case, the water electrolysis stacks 11 are replaced with the fuel cell stacks, the power distribution control system 14 is replaced with a power generation sharing control system, and the flow of power and hydrogen is reversed.

[0060] In the embodiments described above, the power distribution control system 14 and each functional unit thereof can be configured by hardware such as a circuit device that implements these functions and the like, or can be configured by executing software that implements these functions by a computing unit such as a processor or the like. The same applies to the power generation amount prediction unit 21, the degradation monitoring unit 3, and the management system 41.

Claims

1. A hydrogen production system for producing a hydrogen using a plurality of water electrolysis stacks, comprising:

a power converter that controls a power to be supplied to the water electrolysis stacks; and
a power distribution control unit that controls a power to be distributed to each of the water electrolysis stacks by controlling the power converter, wherein
the power distribution control unit includes an operation plan formulation unit that formulates an operation rotation plan of the water electrolysis stacks based on degradation characteristics indicating a susceptibility of the water electrolysis stacks to degradation,
the power distribution control unit includes a stack operation allocation unit that allocates an operation state of the water electrolysis stacks in the operation rotation plan,
the stack operation allocation unit allocates, as the operation state of the water electrolysis stacks, one of:

an operation priority stack that receives power distribution preferentially over the other water electrolysis stacks over a predetermined period of time;
a stop priority stack that preferentially is stopped longer than the other water electrolysis stacks over a predetermined period of time; and
an intermediate operation stack that receives a distribution of power obtained by subtracting a power supplied to the operation priority stack and a power supplied to the stop priority stack from a total power supplied to each of the water electrolysis stacks.

2. The hydrogen production system according to claim 1, wherein, in the operation rotation plan, the stack operation allocation unit sequentially allocates the operation priority stack, the stop priority stack, and the intermediate operation stack in a first order as the operation state of a first stack among the plurality of water electrolysis stacks, and
in the operation rotation plan, the stack operation allocation unit sequentially allocates the operation priority stack, the stop priority stack, and the intermediate operation stack in a second order different from the first order, as the operation state of a second stack among the plurality of water electrolysis stacks,

the second stack is different from the first stack.

3. The hydrogen production system according to claim 2, wherein, in the operation rotation plan, the stack operation allocation unit allocates the operation state of the first stack in the order of the operation priority stack, the stop priority stack, and the intermediate operation stack,

   and when the operation priority stack is allocated to the first stack, the stack operation allocation unit allocates the operation state other than the operation priority stack to the second stack, and when the stop priority stack is allocated to the first stack, the stack operation allocation unit allocates an operation state other than the stop priority stack to the second stack.

4. The hydrogen production system according to claim 1, wherein the power distribution control unit includes a degradation rate calculation unit that calculates degradation rates of the water electrolysis stacks when executing the operation rotation plan, according to degradation characteristics of the water electrolysis stacks, and
the stack operation allocation unit allocates the operation rotation plan such that a difference of the calculated degradation rates between the water electrolysis stacks is small.

5. The hydrogen production system according to claim 1, wherein the stack operation allocation unit allocates, as the operation state of the water electrolysis stack, any one of the operation priority stack, the stop priority stack, the intermediate operation stack, and a stop stack that is stopped for a predetermined period of time, and
when a low power period occurs in which the power supplied to the water electrolysis stacks is less than a threshold value, the stack operation allocation unit allocates the stop stack as the operation state of any one of the respective water electrolysis stacks during at least a portion of the low power period.

6. The hydrogen production system according to claim 1, wherein

   the water electrolysis stack receives a power from a variable power source that has a power value varying with time,
   the power distribution control unit receives a result of predicting an amount of power generation of the variable power source, and
   the power distribution control unit adjusts a number of the water electrolysis stacks to which the operation priority stacks are allocated according to the predicted amount of power generation.

7. The hydrogen production system according to claim 6, wherein, when the predicted amount of power generation is a first amount of power generation, the power distribution control unit allocates the operation priority stack to a first number of the water electrolysis stacks, and
when the predicted amount of power generation is a second amount of power generation that is smaller than the first amount of power generation, the power distribution control unit allocates the operation priority stack to a second number of the water electrolysis stacks, the second number is smaller than the first number.

8. The hydrogen production system according to claim 1, wherein the power distribution control unit acquires degradation states of the water electrolysis stacks, and
the power distribution control unit allocates the operation states of the water electrolysis stacks according to the acquired degradation states.

9. The hydrogen production system according to claim 8, wherein, for the water electrolysis stack that has a first degradation state as the acquired degradation state, the power distribution control unit restrains a number of times to allocate the intermediate operation stack to a first number of times during a predetermined period of time, and
for the water electrolysis stack that has a second degradation state as the acquired degradation state, the second degradation state has a smaller state of health than that of the first degradation state, the power distribution control unit sets a number of times to allocate the intermediate operation stack to be greater than the first number of times during a predetermined period of time.

10. The hydrogen production system according to claim 6, further comprising:

    a distributor that switches between supplying a supplied power, which is supplied from the variable power source, to the water electrolysis stacks, and outputting the same to a power transmission and distribution system, and;
    a management system in which the distributor controls a ratio of distributing the supplied power to the water electrolysis stack and to the power transmission and distribution system according to a power demand.

11. The hydrogen production system according to claim 10, wherein the power distribution control unit receives a result of predicting an amount of power generation of the variable power source, and

    when the predicted amount of power generation is a first amount of power generation, the management system controls the distributor so as to output a first ratio of the supplied power to the power transmission and distribution system, and when the predicted amount of power generation is a second amount of power generation that is smaller than the first amount of power generation, the management system controls the distributor so as to output a second ratio of the supplied power that is smaller than the first ratio to the power transmission and distribution system.

12. The hydrogen production system according to claim 10, wherein, when the power demand is for a first amount of power, the management system controls the distributor so as to output a first ratio of the supplied power to the power transmission and distribution system, and
when the power demand is for a second amount of power that is smaller than the first amount of power, the management system controls the distributor so as to output a second ratio of the supplied power that is smaller than the first ratio to the power transmission and distribution system.

13. The hydrogen production system according to claim 10, wherein the management system controls the ratio according to a heat demand, a supply amount of heat to be supplied according to the heat demand, a hydrogen demand, and a supply amount of hydrogen to be supplied by the hydrogen production system.

14. A hydrogen production method for producing a hydrogen using a plurality of water electrolysis stacks, comprising:

controlling a power converter that controls a power to be supplied to the water electrolysis stacks so as to control a power distributed to each of the water electrolysis stacks, wherein the controlling the power converter includes:

formulating an operation rotation plan of the water electrolysis stacks based on degradation characteristics indicating a susceptibility of the water electrolysis stacks to degradation; and
allocating operation states of the water electrolysis stacks in the operation rotation plan, wherein the allocating the operation states of the water electrolysis stacks includes allocating, as the operation states of the water electrolysis stacks, any one of:

an operation priority stack that receives power distribution preferentially over the other water electrolysis stacks over a predetermined period of time;
a stop priority stack that preferentially is stopped longer than the other water electrolysis stacks over a predetermined period of time; and
an intermediate operation stack that receives a distribution of power obtained by subtracting a power supplied to the operation priority stack and a power supplied to the stop priority stack from a total power supplied to each of the water electrolysis stacks.

FIG. 1

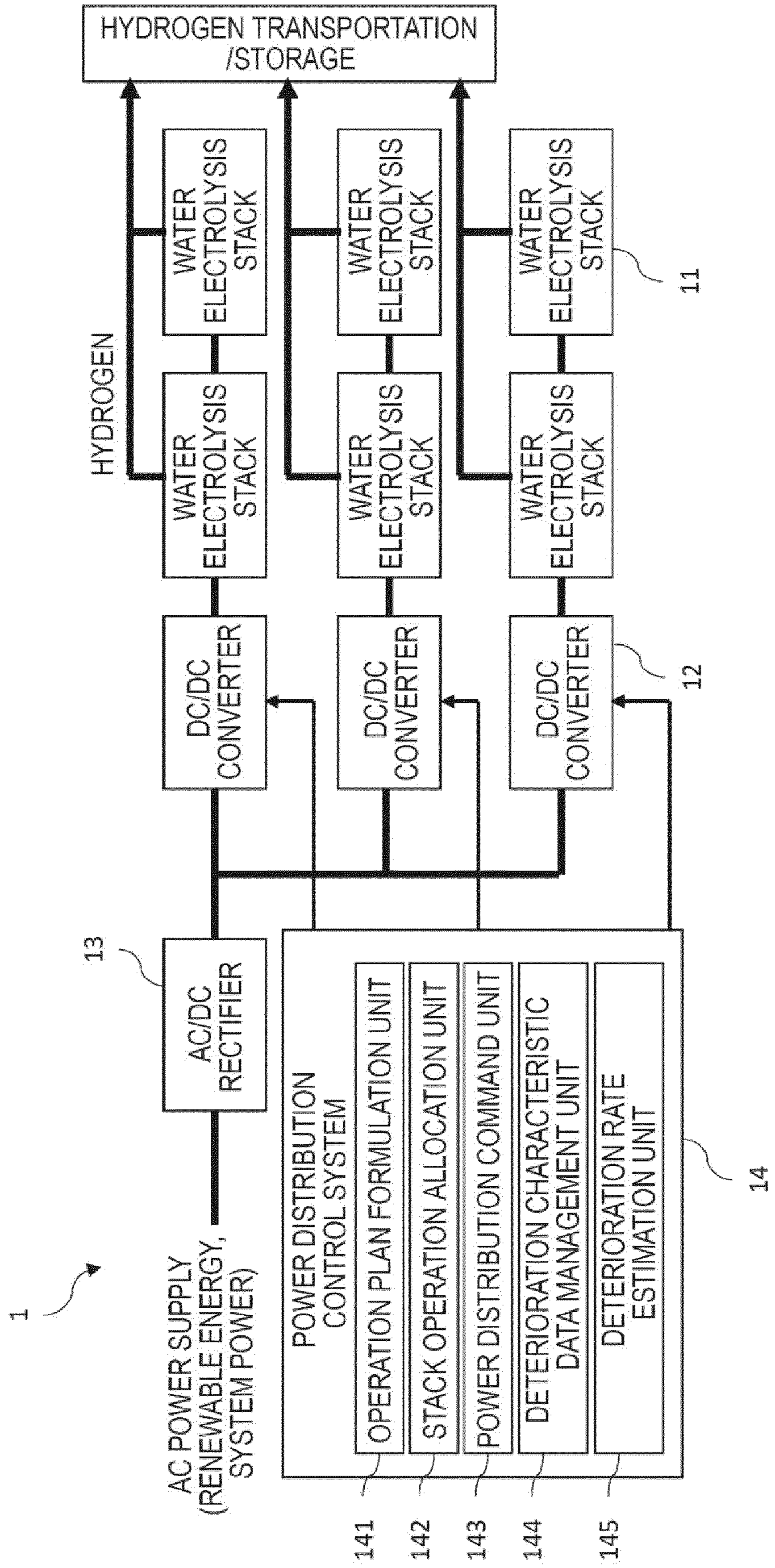
HYDROGEN TRANSPORTATION /STORAGE
HYDROGEN
WATER ELECTROLYSIS STACK
WATER ELECTROLYSIS STACK
WATER ELECTROLYSIS STACK
WATER ELECTROLYSIS STACK
WATER ELECTROLYSIS STACK
WATER ELECTROLYSIS STACK
11
DC/DC CONVERTER
DC/DC CONVERTER
DC/DC CONVERTER
12
13
AC/DC RECTIFIER
1
AC POWER SUPPLY (RENEWABLE ENERGY, SYSTEM POWER)
POWER DISTRIBUTION CONTROL SYSTEM
OPERATION PLAN FORMULATION UNIT
STACK OPERATION ALLOCATION UNIT
POWER DISTRIBUTION COMMAND UNIT
DETERIORATION CHARACTERISTIC DATA MANAGEMENT UNIT
DETERIORATION RATE ESTIMATION UNIT
14
141
142
143
144
145

FIG. 2

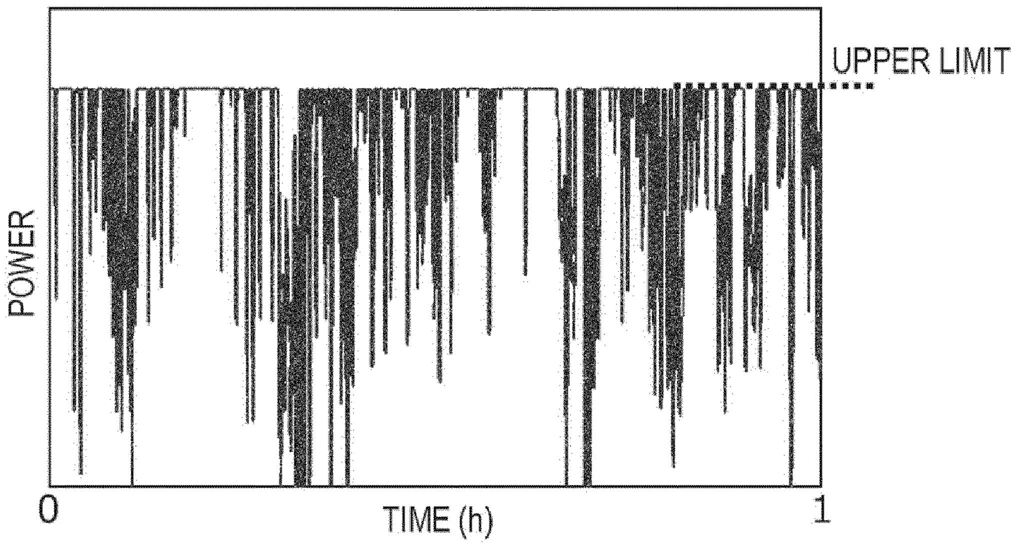

FIG. 3

TIME	A・B	C・D	E・F	G・H
0~6h	OPERATION PRIORITY	INTERMEDIATE	INTERMEDIATE	STOP PRIORITY
6~12h	STOP PRIORITY	OPERATION PRIORITY	INTERMEDIATE	INTERMEDIATE
12~18h	INTERMEDIATE	STOP PRIORITY	OPERATION PRIORITY	INTERMEDIATE
18~24h	INTERMEDIATE	INTERMEDIATE	STOP PRIORITY	OPERATION PRIORITY

FIG. 4A

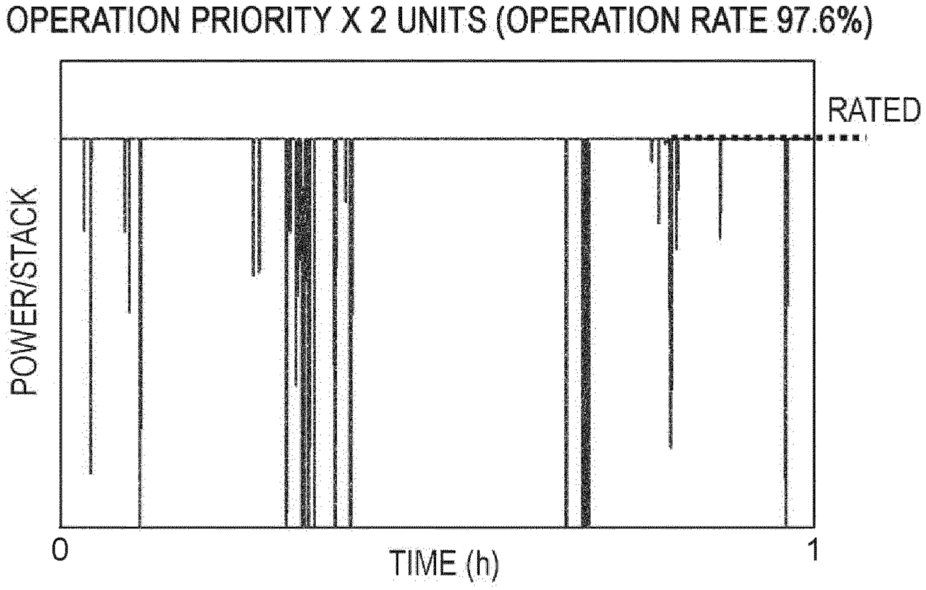
OPERATION PRIORITY X 2 UNITS (OPERATION RATE 97.6%)
RATED
POWER/STACK
0
TIME (h)
1

FIG. 4B

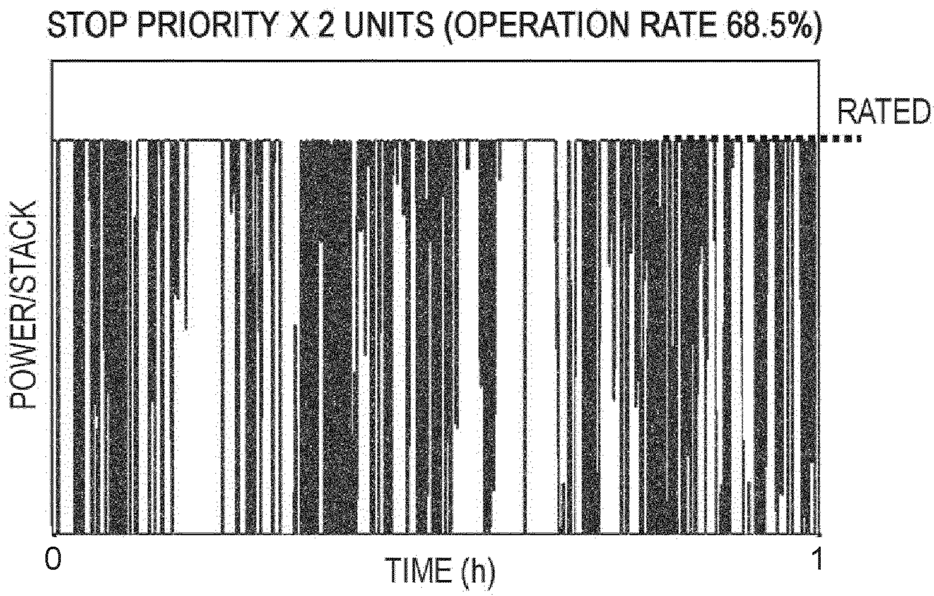
STOP PRIORITY X 2 UNITS (OPERATION RATE 68.5%)
RATED
POWER/STACK
0
TIME (h)
1

FIG. 4C

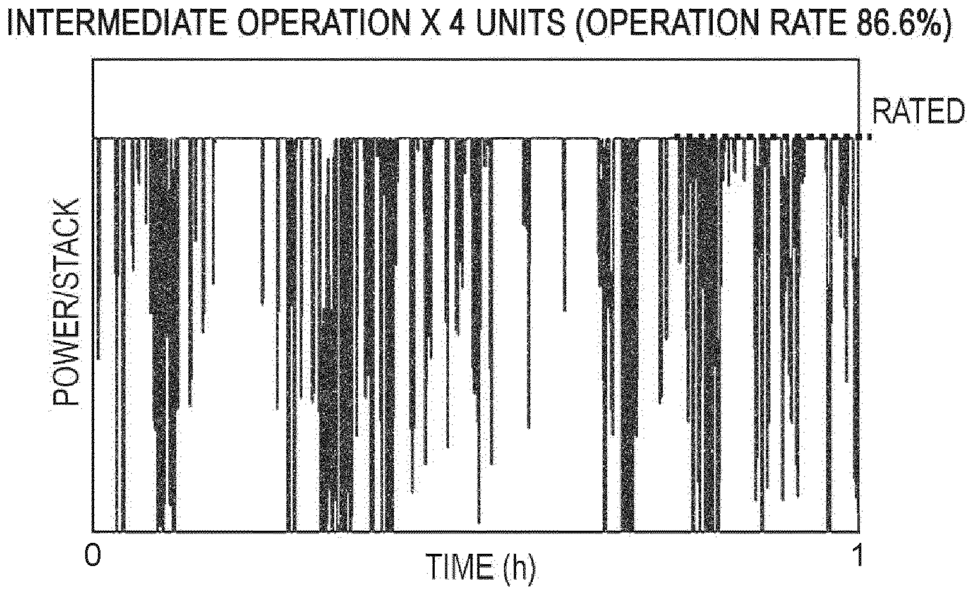
INTERMEDIATE OPERATION X 4 UNITS (OPERATION RATE 86.6%)
RATED
POWER/STACK
0
TIME (h)
1

FIG. 5

MODE	TEST CONDITION	CURRENT DENSITY (A/cm^2)	PERIOD	VOLTAGE RISE RATE (μV/h)
A	CONSTANT CURRENT	1	1009 h	0
B	CONSTANT CURRENT	2	1009 h	194
C	CURRENT CYCLE	2 - 1	6 h - 6 h	65
D	CURRENT CYCLE	2 - 0	6 h - 6 h	16
E	CURRENT CYCLE	2 - 0	10 min - 10 min	50

FIG. 6

TIME	A•B	C•D	E•F
0~6h	OPERATION PRIORITY	INTERMEDIATE OPERATION	STOP PRIORITY
6~12h	STOP PRIORITY	OPERATION PRIORITY	INTERMEDIATE OPERATION
12~18h	INTERMEDIATE OPERATION	STOP PRIORITY	OPERATION PRIORITY

FIG. 7A

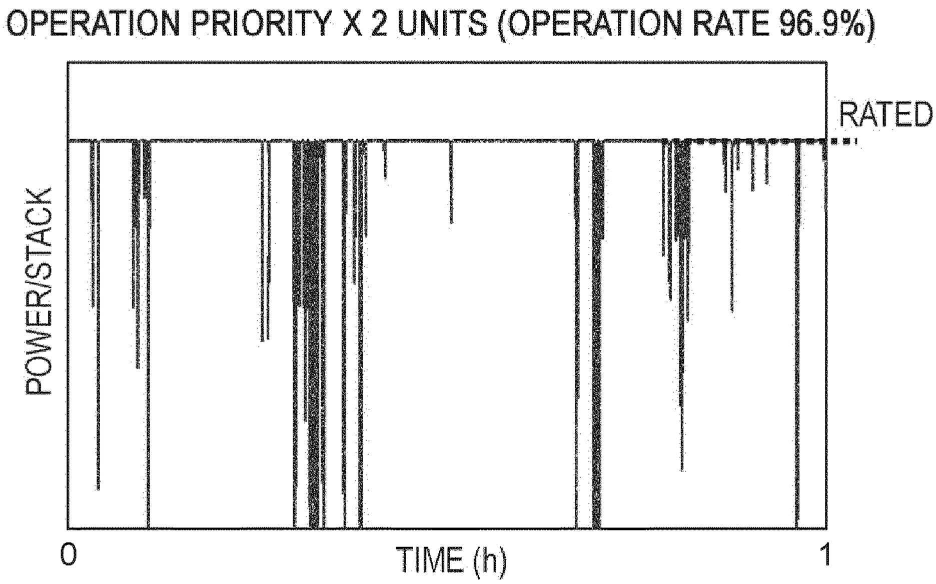
OPERATION PRIORITY X 2 UNITS (OPERATION RATE 96.9%)
RATED
POWER/STACK
0
TIME (h)
1

FIG. 7B

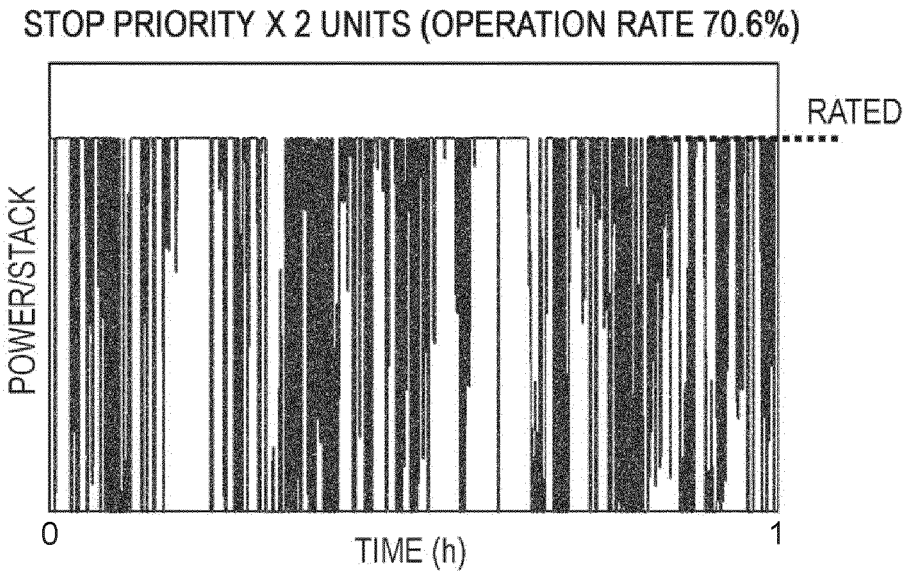
STOP PRIORITY X 2 UNITS (OPERATION RATE 70.6%)
RATED
POWER/STACK
0
TIME (h)
1

FIG. 7C

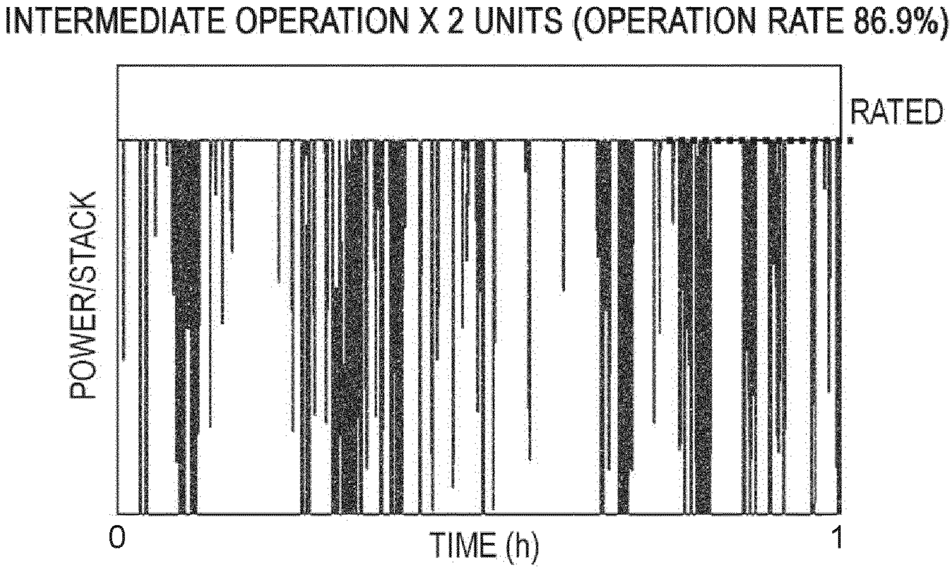
INTERMEDIATE OPERATION X 2 UNITS (OPERATION RATE 86.9%)
RATED
POWER/STACK
0
TIME (h)
1

FIG. 8

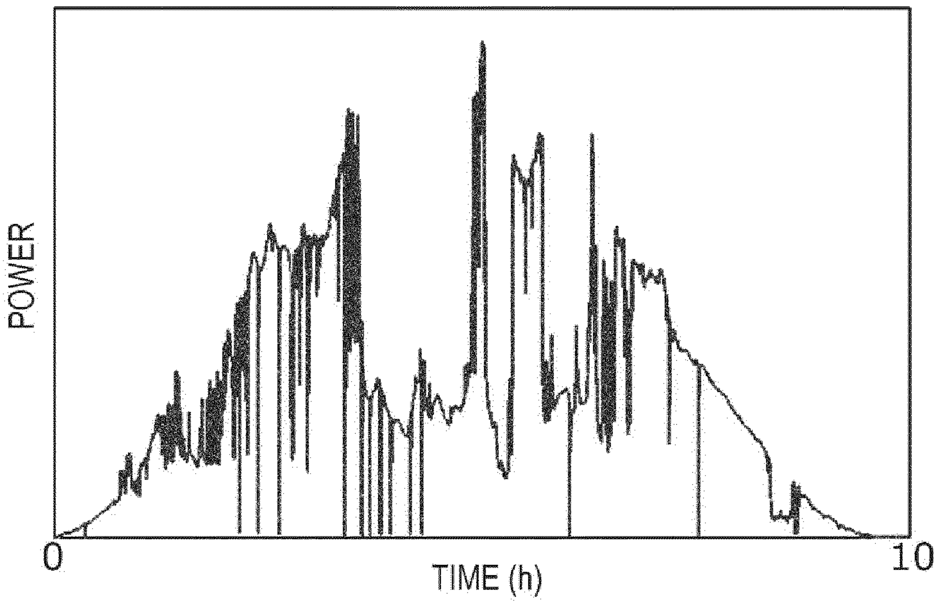
POWER
0
TIME (h)
10

FIG. 9

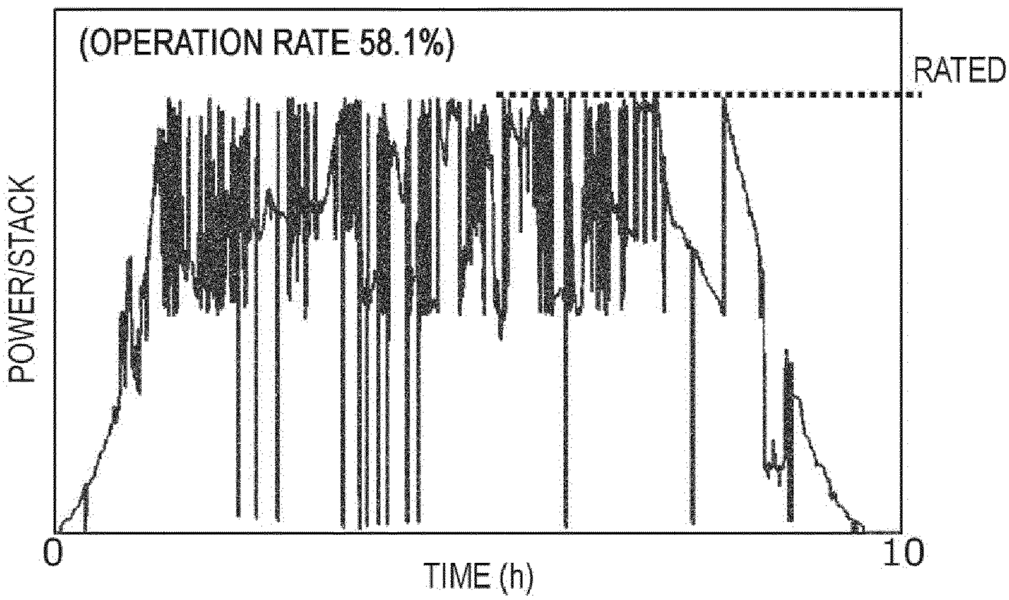
(OPERATION RATE 58.1%)
RATED
POWER/STACK
0
TIME (h)
10

FIG. 10

TIME	A・B	C・D	E・F	G・H
0~2h	OPERATION PRIORITY	INTERMEDIATE OPERATION	OFF	OFF
2~4h	STOP PRIORITY	OPERATION PRIORITY	INTERMEDIATE OPERATION	INTERMEDIATE OPERATION
4~6h	INTERMEDIATE OPERATION	STOP PRIORITY	OPERATION PRIORITY	INTERMEDIATE OPERATION
6~8h	INTERMEDIATE OPERATION	INTERMEDIATE OPERATION	STOP PRIORITY	OPERATION PRIORITY
8~10h	OPERATION PRIORITY	OFF	OFF	OFF

FIG. 11A

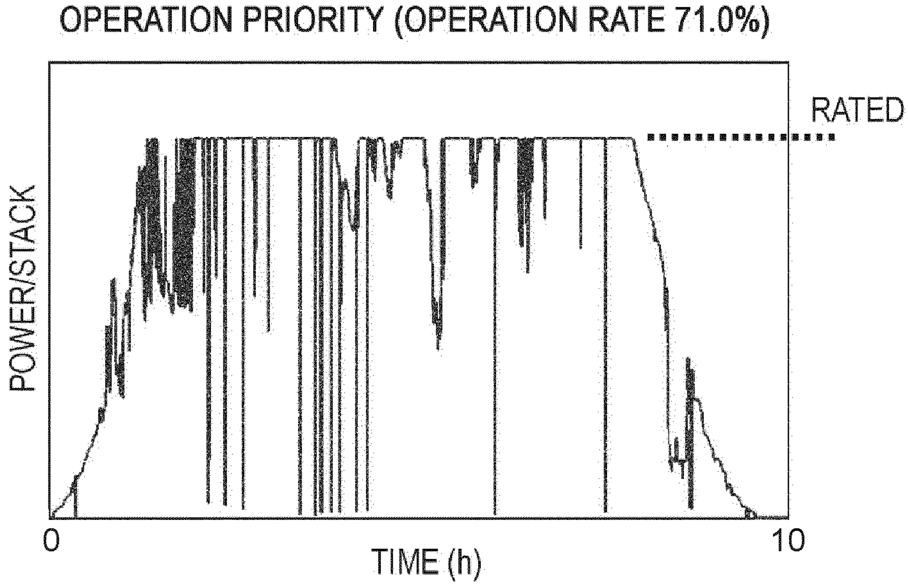

FIG. 11B

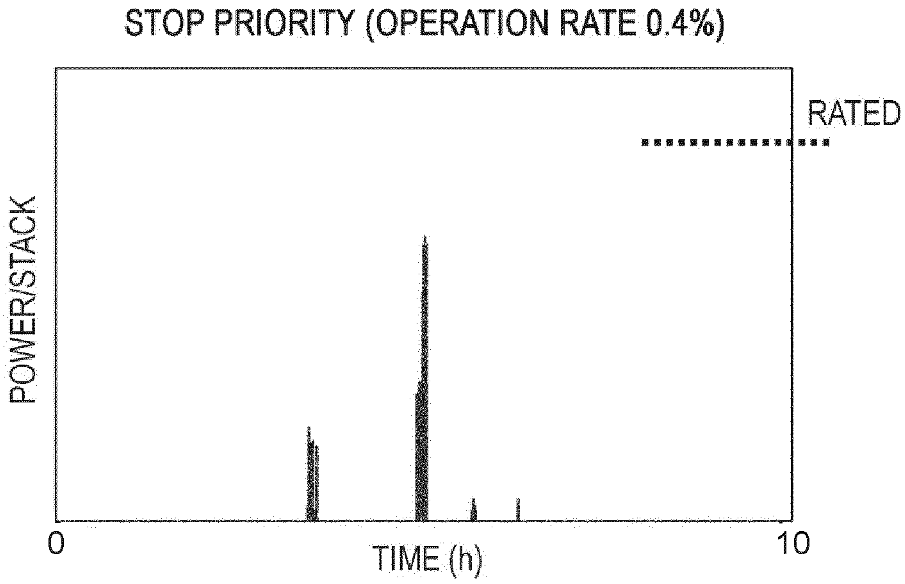

FIG. 11C

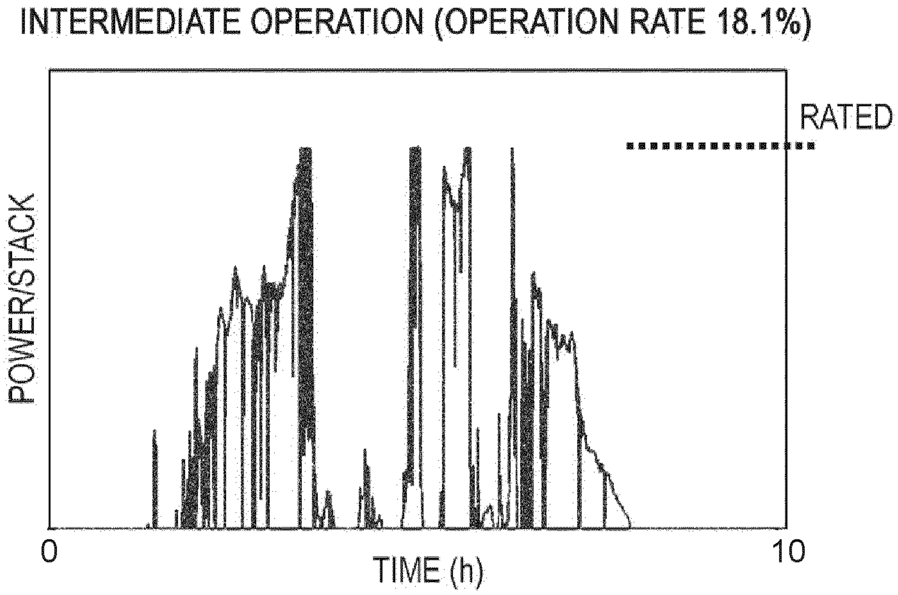
INTERMEDIATE OPERATION (OPERATION RATE 18.1%)
RATED
POWER/STACK
0
10
TIME (h)

FIG. 12

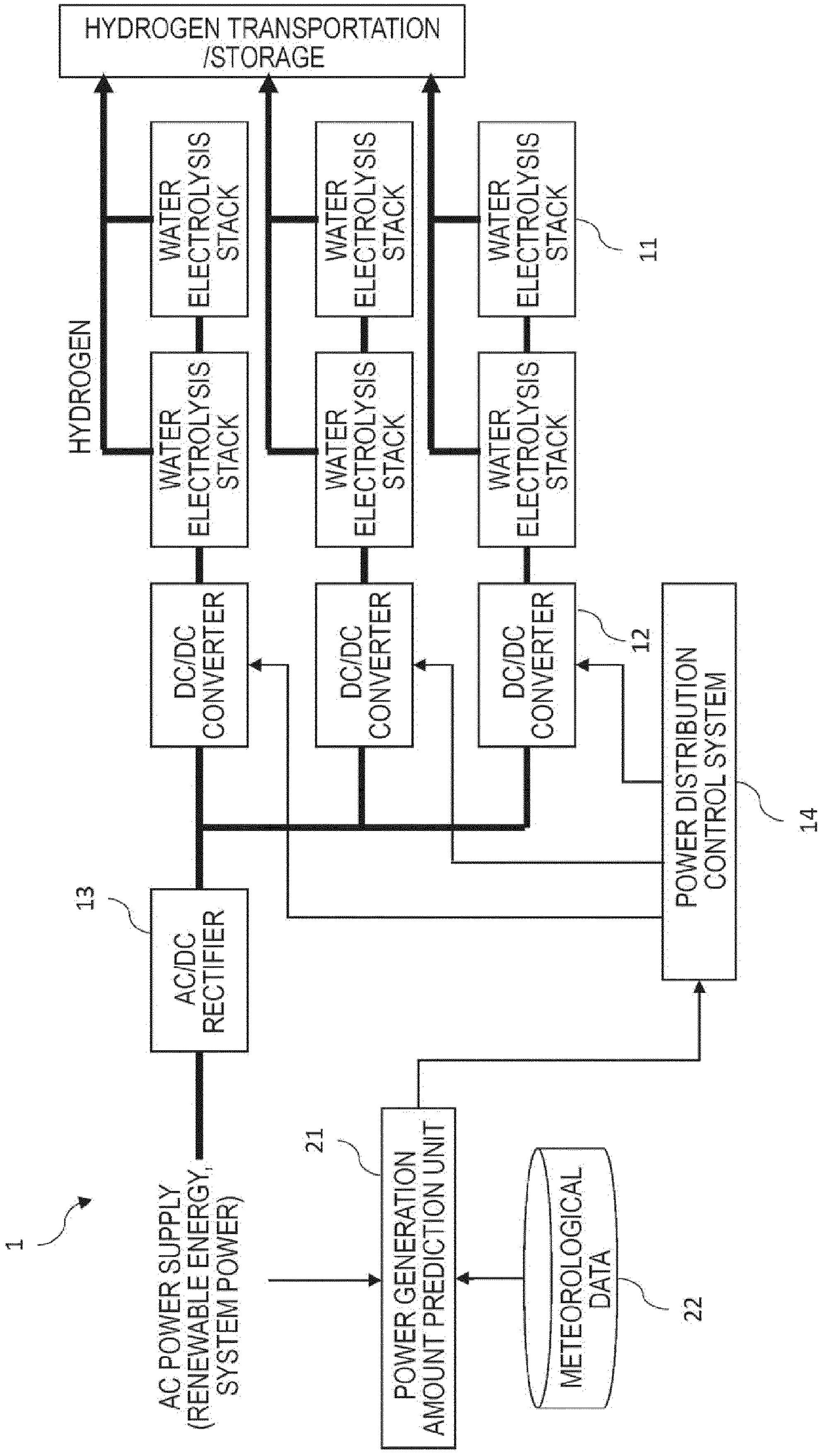
HYDROGEN TRANSPORTATION /STORAGE
HYDROGEN
WATER ELECTROLYSIS STACK
WATER ELECTROLYSIS STACK
WATER ELECTROLYSIS STACK
WATER ELECTROLYSIS STACK
WATER ELECTROLYSIS STACK
WATER ELECTROLYSIS STACK
11
DC/DC CONVERTER
DC/DC CONVERTER
DC/DC CONVERTER
12
POWER DISTRIBUTION CONTROL SYSTEM
14
13
AC/DC RECTIFIER
1
AC POWER SUPPLY (RENEWABLE ENERGY, SYSTEM POWER)
21
POWER GENERATION AMOUNT PREDICTION UNIT
METEOROLOGICAL DATA
22

FIG. 13

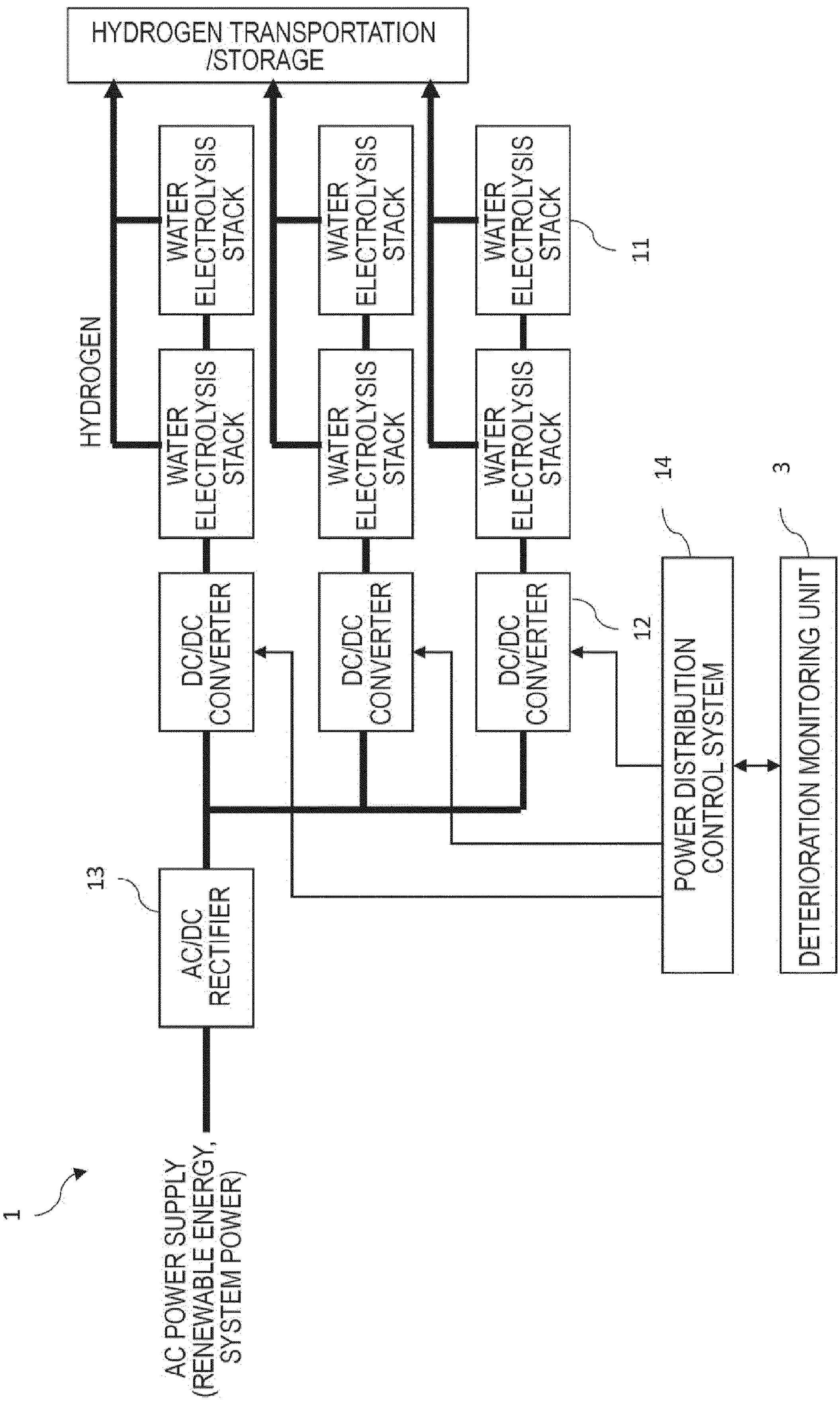
1
AC POWER SUPPLY (RENEWABLE ENERGY, SYSTEM POWER)
AC/DC RECTIFIER
13
DC/DC CONVERTER
DC/DC CONVERTER
DC/DC CONVERTER
12
WATER ELECTROLYSIS STACK
WATER ELECTROLYSIS STACK
WATER ELECTROLYSIS STACK
WATER ELECTROLYSIS STACK
WATER ELECTROLYSIS STACK
WATER ELECTROLYSIS STACK
11
HYDROGEN
HYDROGEN TRANSPORTATION /STORAGE
POWER DISTRIBUTION CONTROL SYSTEM
14
DETERIORATION MONITORING UNIT
3

FIG. 14

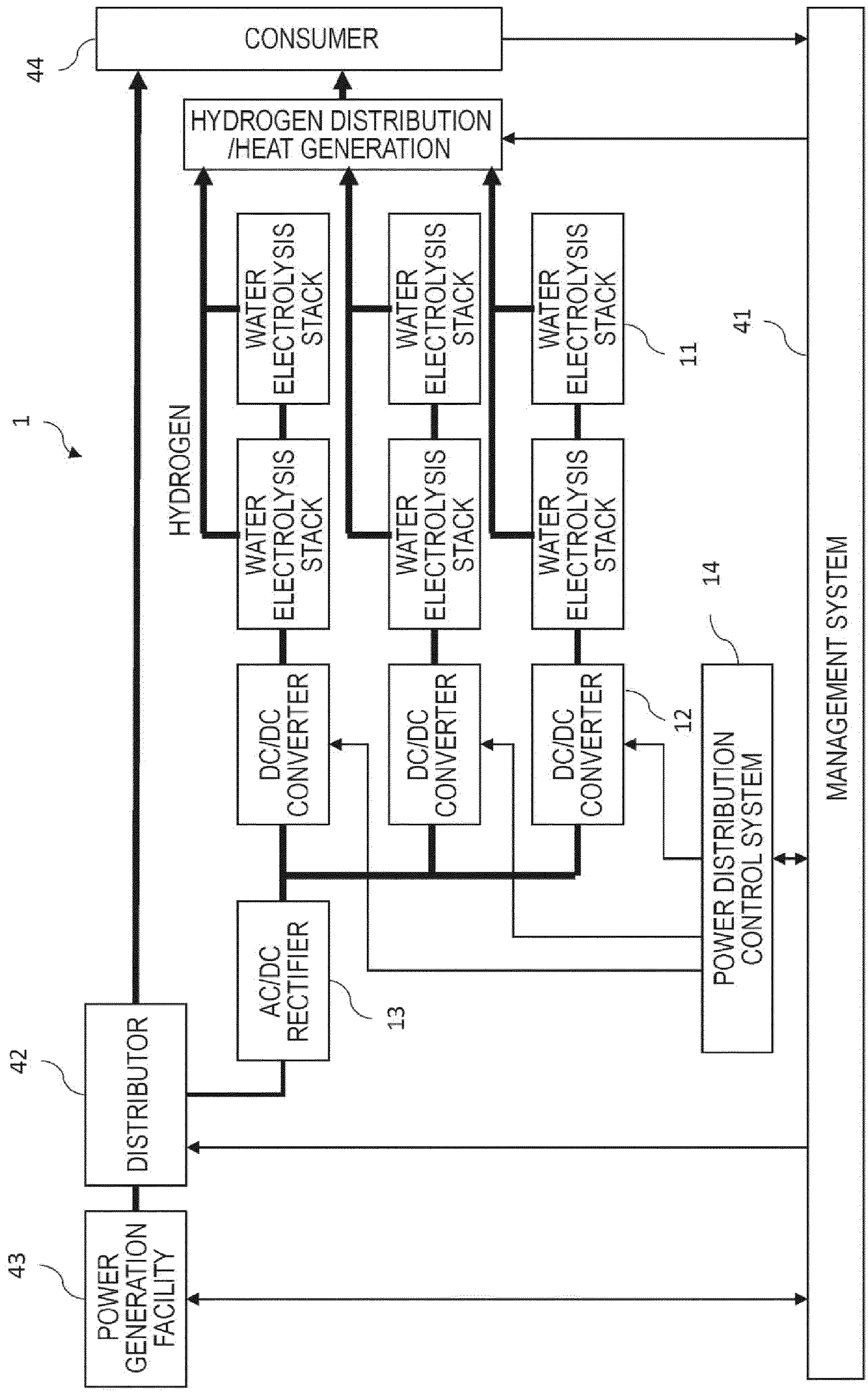
CONSUMER
44
HYDROGEN DISTRIBUTION /HEAT GENERATION
WATER ELECTROLYSIS STACK
WATER ELECTROLYSIS STACK
WATER ELECTROLYSIS STACK
WATER ELECTROLYSIS STACK
WATER ELECTROLYSIS STACK
WATER ELECTROLYSIS STACK
HYDROGEN
1
11
41
14
12
DC/DC CONVERTER
DC/DC CONVERTER
DC/DC CONVERTER
AC/DC RECTIFIER
13
POWER DISTRIBUTION CONTROL SYSTEM
MANAGEMENT SYSTEM
DISTRIBUTOR
42
POWER GENERATION FACILITY
43

FIG. 15

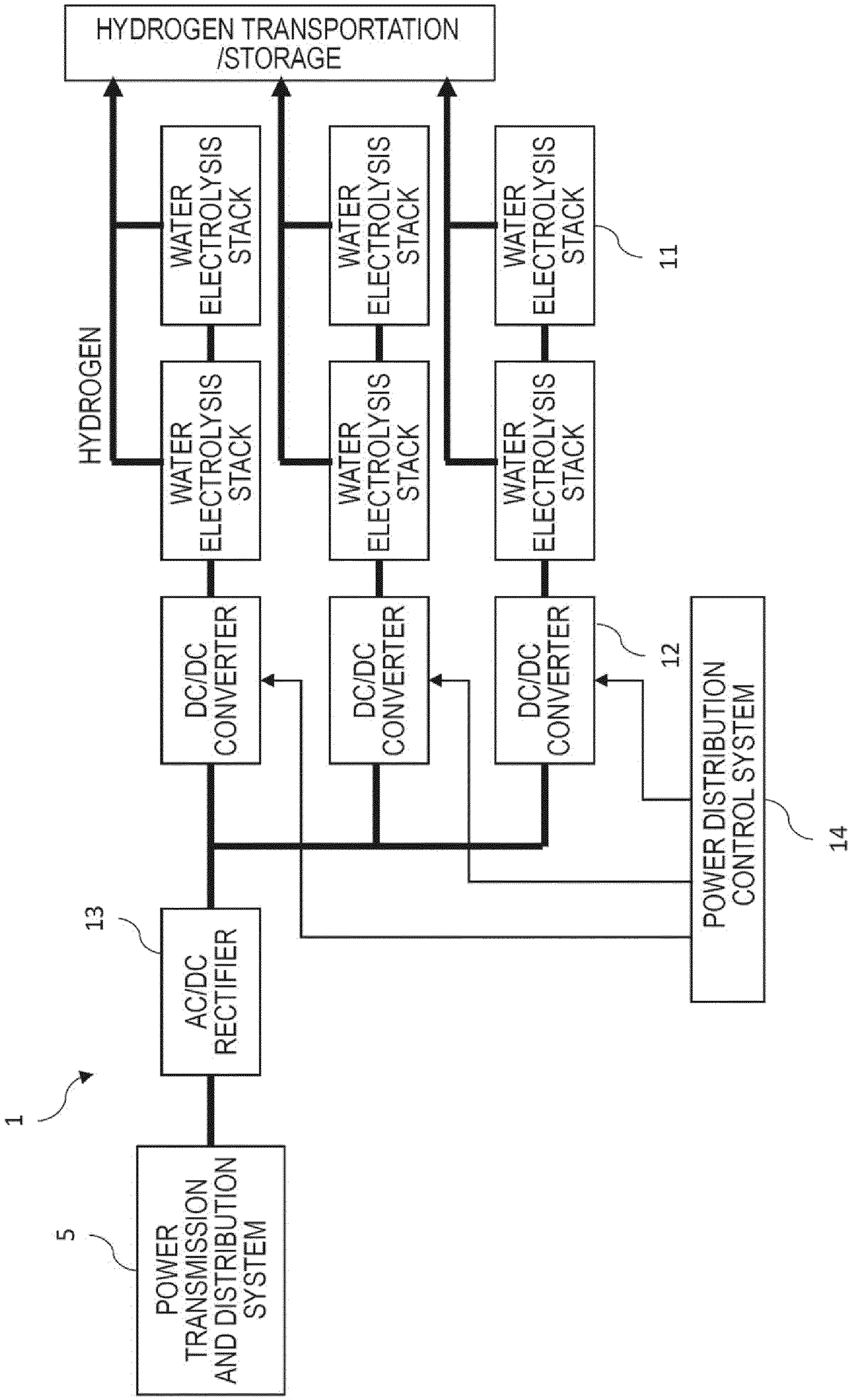
HYDROGEN TRANSPORTATION /STORAGE
HYDROGEN
WATER ELECTROLYSIS STACK
WATER ELECTROLYSIS STACK
WATER ELECTROLYSIS STACK
WATER ELECTROLYSIS STACK
WATER ELECTROLYSIS STACK
WATER ELECTROLYSIS STACK
11
DC/DC CONVERTER
DC/DC CONVERTER
DC/DC CONVERTER
12
POWER DISTRIBUTION CONTROL SYSTEM
14
13
AC/DC RECTIFIER
1
5
POWER TRANSMISSION AND DISTRIBUTION SYSTEM

FIG. 16A

TIME	A・B	C・D	E・F	G・H
0~6h	1.4	1.4	1.4	1.4
6~12h	1.4	1.4	1.4	1.4
12~18h	1.4	1.4	1.4	1.4
18~24h	1.4	1.4	1.4	1.4

FIG. 16B

TIME	A・B	C・D	E・F	G・H
0~6h	1.8	1.0	1.8	1.0
6~12h	1.0	1.8	1.0	1.8
12~18h	1.8	1.0	1.8	1.0
18~24h	1.0	1.8	1.0	1.8

REFERENCES CITED IN THE DESCRIPTION

Patent documents cited in the description

- JP 2020084259 A **[0006]**

Non-patent literature cited in the description

- **C. RAKOUSKY et al.** *Power Sources,* 2017, vol. 342, 38 **[0005]**