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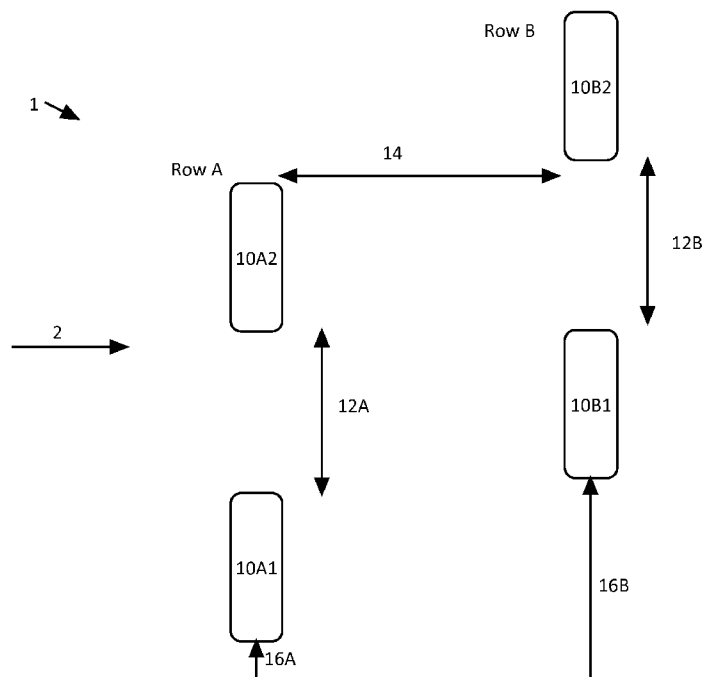
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(54) Title: WATER CURRENT TURBINE ARRANGEMENTS AND GROUP CONTROL



(57) Abstract: A method is described for controlling a water current turbine array (1) which includes first and second pluralities (row A, row B) of water current turbines (10) operable to generate electricity from a water current. The method comprises controlling respective power generation characteristics of the water current turbines in the array so as to maximise power generation of the array (1) as a whole.

FIGURE 1

WATER CURRENT TURBINE ARRANGEMENTS AND GROUP CONTROL

The present invention relates to water current turbine arrangements, and, in particular, to a control scheme for water current turbine arrangements.

BACKGROUND OF THE INVENTION

5 It is widely known that easily accessible resources of fossil fuels are declining. In addition, the impact of the use of fossil fuels upon the environment has become increasingly apparent. As a result of this, it has become imperative that viable alternative energy sources are used as effectively and efficiently as possible. The use of turbines to capture the power of water flow, such as tidal, river and ocean current flows is becoming a viable source of alternative
10 energy. The turbine equipment used to capture such water flow energy typically includes a shaft driven generator connected using a drivetrain to a rotor assembly. The rotor assembly includes a plurality of rotor blades that are driven by the water flow, so as to turn an input shaft of the drivetrain.

In order to be economically practical, multiple water current turbine devices need to be
15 deployed in a suitable area. For example, a tidal turbine farm may have tens to hundreds of turbines. The turbines are preferably arranged in an array having multiple rows of multiple turbines. Figure 1 of the accompanying drawings illustrates, in very simplified schematic form, a plan view of a turbine array 1. The turbine array 1 could be deployed in a tidal flow area, a river flow, an ocean current, or any other suitable water current area. Although it is
20 preferable for the turbines to be arranged in an array, geography, bathymetry and other factors may mean that a turbine farm has another arrangement.

The exemplary turbine array 1 of Figure 1 comprises two rows (A and B) of two turbines 10A1, 10A2 and 10B1, 10B2 respectively. The number of turbines shown in Figure 1 has been limited to two in each row for the sake of clarity and simplicity. Similarly, the number of
25 rows has been reduced to show the minimum number needed to form an array. It will be readily appreciated that a practical array could have any number of rows, and any number of turbines per row. In Figure 1, a water current is indicated by arrow 2, and flows in a direction such that Row A is upstream of Row B.

The turbines in a row are spaced apart from one another by a turbine spacing 12A, 12B for
30 the row concerned. This spacing may be the same for each row, or may vary between rows, and is to be considered a nominal value, as the exact spacing of turbines along a row is dependent on many factors including the nature of the bed on which the turbines are located.

The rows are spaced apart by a row spacing 14, and, again, this spacing may be the same between each pair of adjacent rows in the array, or could vary across the array. As for turbine spacing, the row spacing is to be considered a nominal value. In addition, the row spacing can vary along the rows.

- 5 The first turbine 10A1 in Row A is spaced from an arbitrary datum by a first offset value 16A, whilst the first turbine 10B1 of Row B is offset by a second offset value 16B. The first and second offset values 16A, 16B may be substantially equal to one another, in which case the turbine would effectively be lined up behind one another in the array, with respect to the direction of the flow. In a more practical example, however, the first and second offset
- 10 values 16A, 16B would be different. Such different offset values leads to the turbines in Row B being offset, or staggered, with reference to the turbines in Row A. Such a situation is illustrated in Figure 1.

One way to increase the energy yield of a water current turbine array, such as that shown in Figure 1, is simply to increase the number of water current turbines in the array, by packing

15 the turbines more closely; the turbine spacing along the row, and, in particular, the row spacing could be reduced. In such a way the number of turbines in a given area (the "packing density") is increased and therefore the amount of energy that can be captured from the flow is increased. This is the case when the flow speed of the current is high enough to provide more energy than needed for all of the turbines to produce a constant

20 rated power level. As is well known, when the flow speed is over a threshold level (a "rated level"), the turbines are controlled to produce a constant rated power output.

However, as the flow speed drops below the rated level, the amount of energy in the flow decreases. In this case some, or all, of the turbines are not able to generate the rated power output. Upstream turbines affect the amount of energy available for capture by downstream

25 turbines, and the amount of energy available to the downstream turbines decreases as the row spacing decreases. It will be appreciated that downstream in the current context is any position having a component in the direction of the flow.

Previously-considered control schemes for such turbine farms work on the principle of maximising power generation for each turbine, ignoring any effects on other turbines in the

30 array. In this previously-considered control scheme, all turbines are controlled to generate maximum power. However, this may result in downstream turbines failing to generate a desirably high level of power, and, for example, not being able to run at ideal operating conditions. One such previously-considered scheme is described in European Patent Application 09005504.7, published as EP 2 241 749, in which each individual turbine is

controlled in order to maximise from that turbine, and that turbine only, without consideration of any of the other turbines in the array.

Accordingly, it is desirable to be able to overcome the disadvantages of previously-considered schemes.

5 SUMMARY OF THE INVENTION

According to a first aspect of the invention there is provided a method for controlling a water current turbine arrangement which includes first and second pluralities of water current turbines operable to generate electricity from a water current, the first plurality of water current turbines being upstream of at least one of the turbines in the second plurality, the
10 water current turbines having respective individual power generation characteristics, the method comprising independently controlling the individual power generation characteristics of each of the water current turbines in the arrangement so as to maximise overall energy capture from the arrangement as a whole.

The first and second pluralities of water current turbines may be arranged in respective first
15 and second rows, so as to form an array.

Such a method may further comprise receiving measurement information indicative of respective power generation characteristics of the turbines, and using received measurement information in controlling the turbines.

Such a method may comprise controlling the power generation characteristics of the first
20 plurality of water current turbines independently of the power generation characteristics of the second plurality of water current turbines. Alternatively, such a method may comprise defining groups of water current turbines, and controlling the power generation characteristics of water current turbines in one such group independently of turbines in another group.

25 The water current turbine array may include at least one additional plurality of water current turbines arranged in an additional row of the array.

According to a second aspect of the present invention, there is provided a controller for controlling a water current turbine arrangement which includes first and second pluralities of water current turbines operable to generate electricity from a water current, the first plurality
30 of water current turbines being upstream of at least one of the turbines in the second plurality, the water current turbines having respective individual power generation characteristics, the controller comprising a control unit operable to generate and output

control signals relating to respective individual power generation characteristics for water current turbines in such an arrangement, such control signals serving to overall maximise power generation from the arrangement as a whole.

5 Such a controller may further comprise a measurement receiver unit operable to receive measurement information indicative of respective power generation characteristics of the turbines, the control unit being operable to use received measurement information in generating the control signals relating to power generation characteristics.

10 Such a controller may be operable to generate and output respective control signals to such a first plurality of water current turbines independently of generating and outputting respective control signals to such a second plurality of water current turbines.

Alternatively, such a controller may be operable to define groups of water current turbines, and to generate and output respective control signals to water current turbines in one such group independently of turbines in another such group.

15 According to a third of the present invention, there is provided a water current turbine arrangement comprising first and second pluralities of water current turbines operable to generate electricity from a water current, the first plurality of water current turbines being upstream of at least one of the turbines in the second plurality, and such a controller, the controller being connected with each of the turbines in the arrangement for control thereof.

20 The first and second pluralities of water current turbines may be arranged in respective first and second rows, so as to form an array.

Such a water current turbine array may further comprise at least one additional plurality of water current turbines arranged in at least one additional row of the array.

BRIEF DESCRIPTION OF THE DRAWINGS

25 Figure 1 is a schematic plan view of a simplified water current turbine array;

Figure 2 is a schematic view of a water current turbine embodying one aspect of the present invention;

Figure 3 is a schematic view of a control system embodying another aspect of the present invention for a water current turbine array;

Figure 4 is a flow chart illustrating steps in the method embodying another aspect of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

- 5 Figure 2 is a block diagram of a water current turbine 10 embodying one aspect of the present invention, for use in a water current turbine array, such as that illustrated in Figure 1. The water current turbine 10 includes a rotor assembly 20, which is arranged to be driven by the water current. The rotor assembly 20 rotates a shaft that transmits power to an electrical generator 22, which operates to generate electricity for supply to the power grid.
- 10 The water current turbine 10 is provided with a controller unit 24, which operates to control the power generation characteristics of the electrical generator 22, so that the generator provides a required electrical power output. A measurement unit 26 is provided for monitoring the generator 22, and for providing measurement information regarding the power generating characteristics of the generator 22, in particular, and of the water current
- 15 turbine 10 in general.

The controller unit 24 and the measurement unit 26 are operable to transfer data with an array control unit (to be described with reference to Figure 4).

- Figure 3 illustrates an array control unit 30 which includes a processor unit 32, which provides the overall processing functionality of the control unit 30. The processor unit 32
- 20 also provides a user interface 38 for interaction with the human controller of the system.

- The array control unit 30 also includes a measurement receiver unit 34 and a control signal transmitter unit 36. The measurement receiver unit 34 is operable to receive measurement information from the measurement units 26 in the water current turbines 10 shown in Figure 2. Operating information may be gathered in any convenient manner, for example, the water
- 25 current turbines may be polled individually at regular intervals, or may themselves operate to transmit information to the measurement receiver unit 34 of the array control unit 30.

- The control signal transmitter unit 36 is operable to transmit control information from the processor unit 32 to the controller units 24 in the water current turbines 10. This control information, as described in more detail below, serves to control the power generating
- 30 characteristics and parameters of the water current turbine 10.

Figure 4 is a flow diagram illustrating steps in a method embodying another aspect of the present invention. At step 100, measurement data is received by the measurement receiver unit 34 from the measurement units 26 in the turbines 10, and this information is transferred to the processor unit 32.

- 5 At step 102, the processor unit 32 compares received measurement information for the turbines 10 across the whole array 1, and calculates control signals for adapting each water current turbine in order to maximise the power generation of the array as a whole. The turbine control information is then transmitted to the controller units 24 of the turbines 10 by the control signal transmitter unit 36.
- 10 The processor unit 32 operates to determine a power generation control scheme for each turbine, such that the overall power generation of the array of turbines as a whole is maximised, optimised, or controlled to meet a particular criterion. For example, the processor unit 32 may determine that selected turbines must operate at a reduced power output level in order that other turbines in the array are able to operate at a level higher than
15 would otherwise be possible. Controlling the turbines individually allows for optimised control for each of the turbines. Using the effects and conditions placed on a given turbine by the other turbines in the array as a source of control information, and then using that information to control the given turbine and the other turbines enables the overall output of the array as a whole to be optimised for the prevailing conditions.
- 20 The control unit 24 in a water current turbine 10 then operates to control the power generating characteristics of that turbine so that the required level of power is generated. This control is achieved by controlling the electrical generator 22 and/or the rotor assembly 20. Other power rating control techniques include hydraulic transmission settings or gearbox ratios.
- 25 For example, the control unit 24 may operate to control pitching of the blades of the rotor assembly 20, and/or may control the electrical torque of the electrical generator 22, such that the power generation characteristics of the water current turbine are adjusted in accordance with the received instructions.

In a practical example, a water current turbine may be rated at 1 MW output power, and an
30 array of such machines may be used to generate electricity from a given water current flow. When the water current flow speeds are low enough such that none of the water current turbines is able to generate the rated 1 MW power, (or when that flow speed is such that only some of the rows of turbines are able to produce the rated power of 1 MW, with

subsequent rows achieving only a proportion of the rated power) then the processor unit 32 operates to control the power output of the turbines such that the power generation of the array of a whole is maximised.

5 In one example, it may be that the control scheme requires that each turbine in the first row (A) is operated at 90% of rated power (in this example 900 kW) such that more energy is available to be captured by the second and subsequent rows. In this way, the overall power generation energy capture of the array can be substantially maximised.

10 In another example, all of the turbines in the array can be controlled to produce the same power output, for example 75% of rated power. In another example, turbines can be controlled in rows; the first row is set to generate power at a particular level, the second at another level, and so on.

15 Alternatively, the turbines may be grouped in other ways, and each grouped controlled separately. For example, those turbines in a central region of the array may form one group, whilst turbines in edge regions of the array could form another group. Since flow conditions may be different between the different groups, in accordance with the principles of the present invention, the different groups can be controlled separately in order to maximise the power generation of the farm as a whole.

20 Such a control scheme enables downstream turbines to operate at a power generation level greater than would be achieved if the upstream turbines are simply controlled to generate maximum power, and the increase in performance of the downstream turbines makes up for, or exceeds, the reduction in power generation of the upstream turbines.

CLAIMS:

1. A method for controlling a water current turbine arrangement which includes first and second pluralities of water current turbines operable to generate electricity from a water current, the first plurality of water current turbines being upstream of at least one of the turbines in the second plurality, the water current turbines having respective individual power generation characteristics, the method comprising independently controlling the individual power generation characteristics of each of the water current turbines in the arrangement so as to maximise overall energy capture from the arrangement as a whole.
2. A method as claimed in claim 1, wherein the first and second pluralities of water current turbines are arranged in respective first and second rows, so as to form an array.
3. A method as claimed in claim 1 or 2, further comprising receiving measurement information indicative of respective individual power generation characteristics of the water current turbines, and using received measurement information in controlling the water current turbines.
4. A method as claimed in claim 1, 2 or 3, comprising controlling the respective individual power generation characteristics of the water current turbines of the first plurality independently of controlling the respective individual power generation characteristics of the water current turbines of the second plurality.
5. A method as claimed in claim 1, 2 or 3, comprising defining groups of water current turbines, and controlling the power generation characteristics of water current turbines in one such group independently of turbines in another group.
6. A method as claimed in any one of the preceding claims, wherein the water current turbine arrangement includes at least one additional plurality of water current turbines.
7. A method as claimed in claim 7, wherein the or each additional plurality of water current turbines is arranged in at least one additional row of the arrangement.
8. A controller for controlling a water current turbine arrangement which includes first and second pluralities of water current turbines operable to generate electricity from a water current, the first plurality of water current turbines being upstream of at least one of the turbines in the second plurality, the water current turbines having

respective individual power generation characteristics, the controller comprising a control unit operable to generate and output control signals relating to respective individual power generation characteristics for water current turbines in such an arrangement, such control signals serving to overall maximise power generation from the arrangement as a whole.

9. A controller as claimed in claim 8, further comprising a measurement receiver unit operable to receive measurement information indicative of respective power generation characteristics of the turbines in the array, the control unit being operable to use received measurement information in generating the power generation characteristic instructions.

10. A controller as claimed in claim 8, operable to generate and output control signals relating to respective power generation characteristics for a first plurality of water current turbines independently of generating and outputting control signals relating to respective power generation characteristics for a second plurality of water current turbines.

11. A controller as claimed in claim 8, operable to define groups of water current turbines, and to generate and output control signals relating to respective power generation characteristics for water current turbines in one such group independently of control signals relating to turbines in another such group.

12. A controller as claimed in any one of claims 8 to 11, operable in accordance with a method as claimed in any one of claims 1 to 7.

13. A water current turbine arrangement comprising first and second pluralities of water current turbines operable to generate electricity from a water current, the first plurality of water current turbines being upstream of at least one of the turbines in the second plurality, and a controller as claimed in any one of claims 8 to 12, the controller being connected with each of the turbines in the arrangement for control thereof.

14. An arrangement as claimed in claim 13, wherein the first and second pluralities of water current turbines are arranged in respective first and second rows, so as to form an array.

15. A water current turbine arrangement as claimed in claim 14, further comprising at least one additional plurality of water current turbines arranged in at least one additional row of the array.

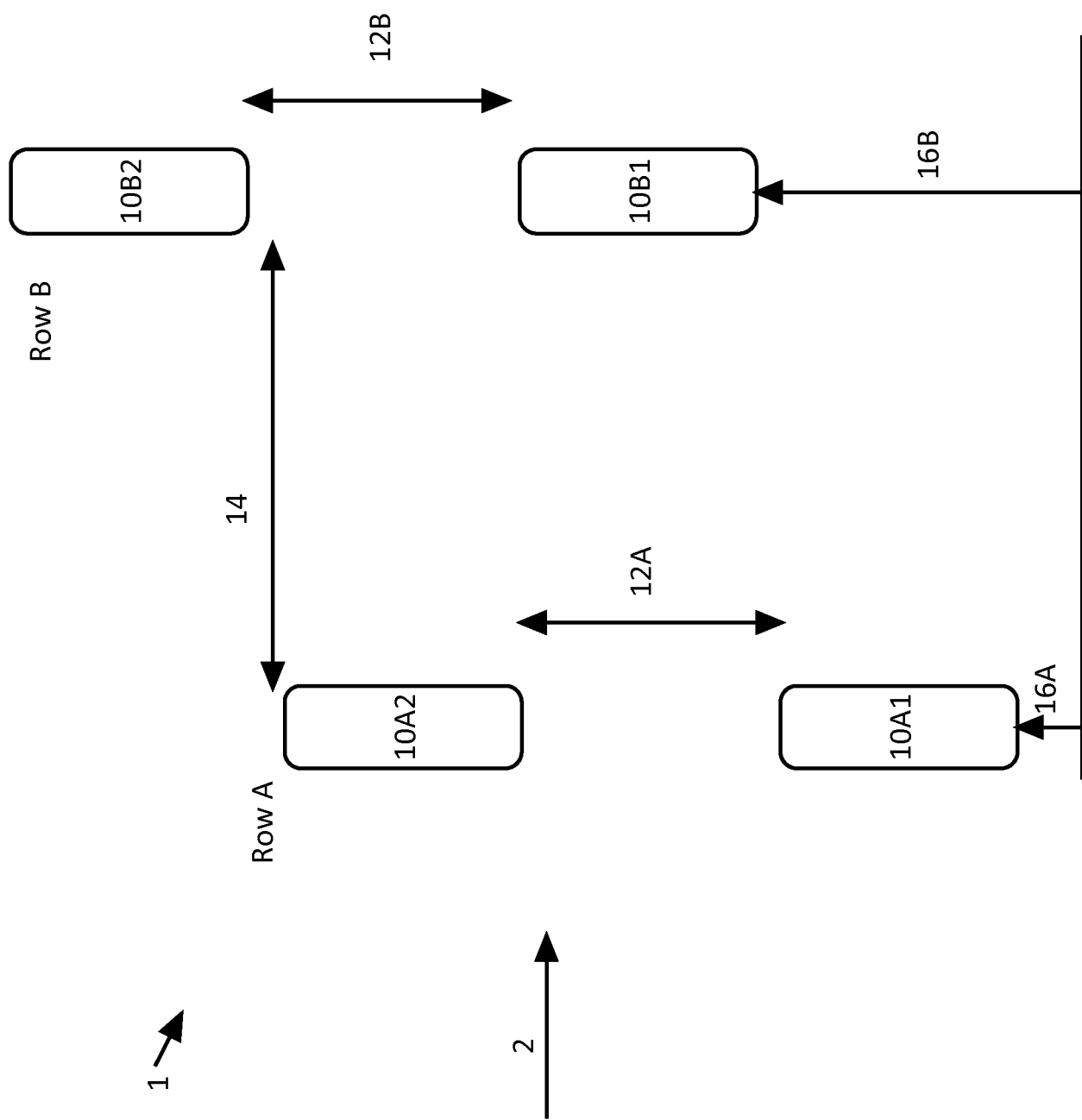


FIGURE 1

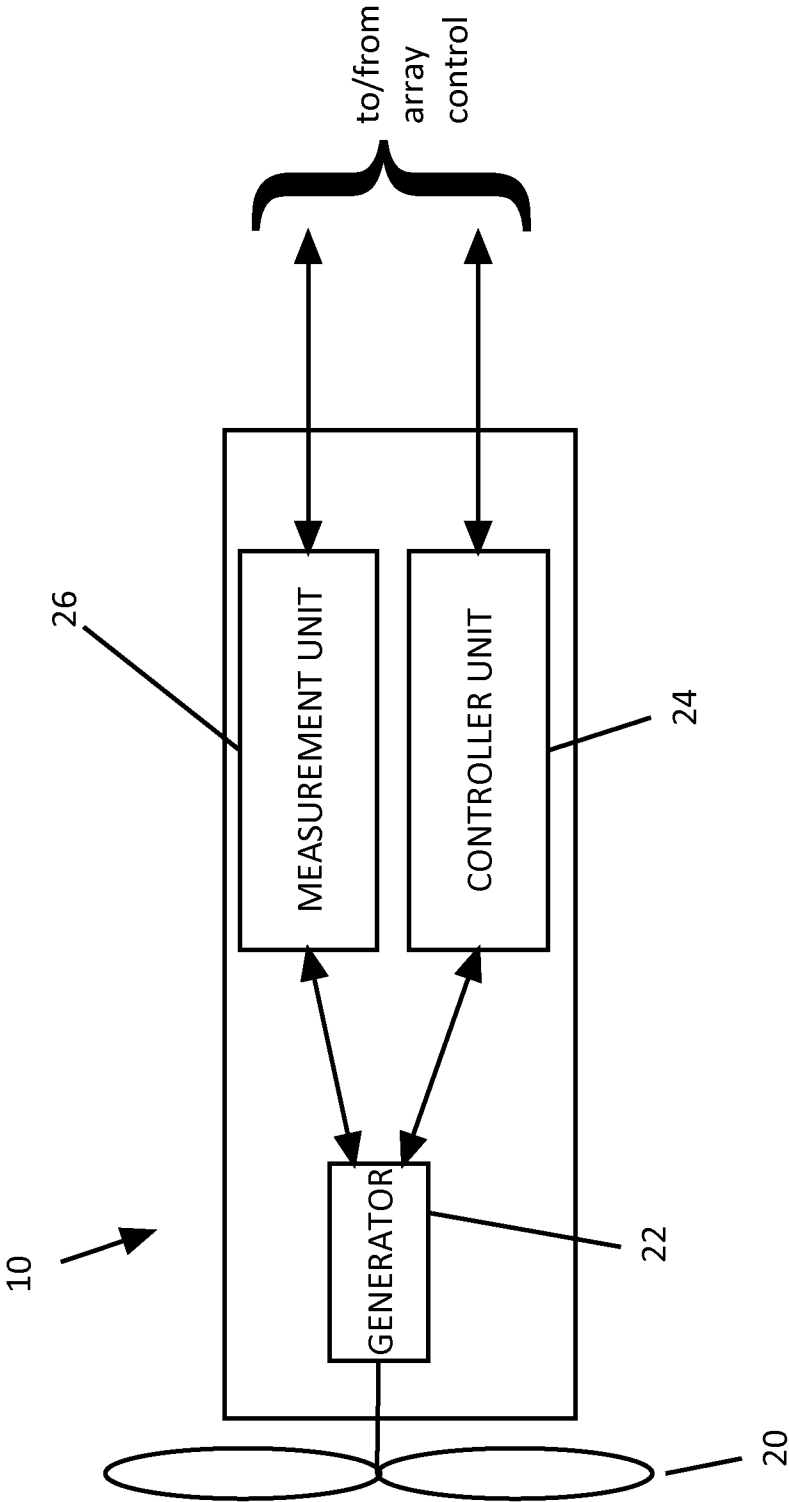


FIGURE 2

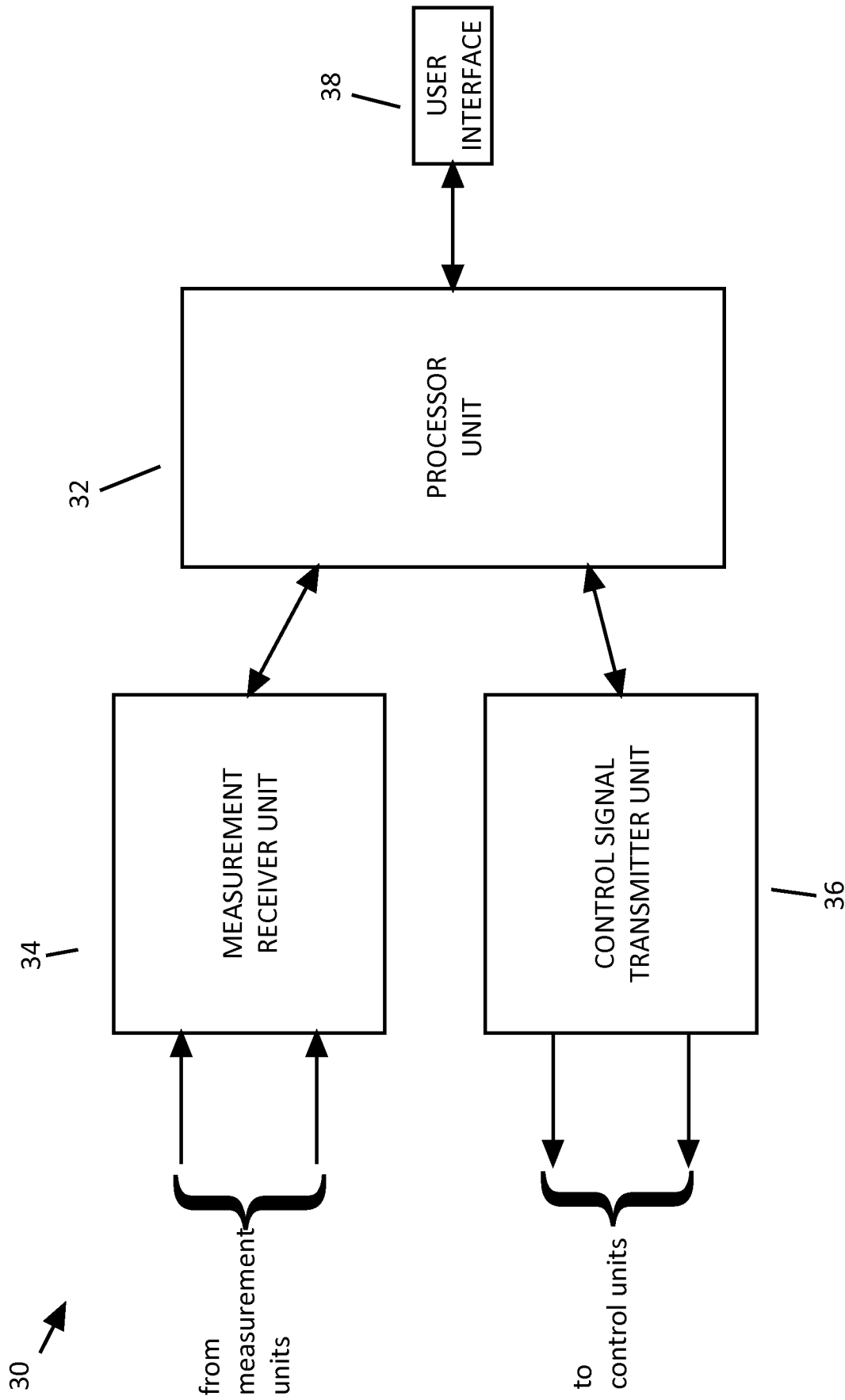


FIGURE 3

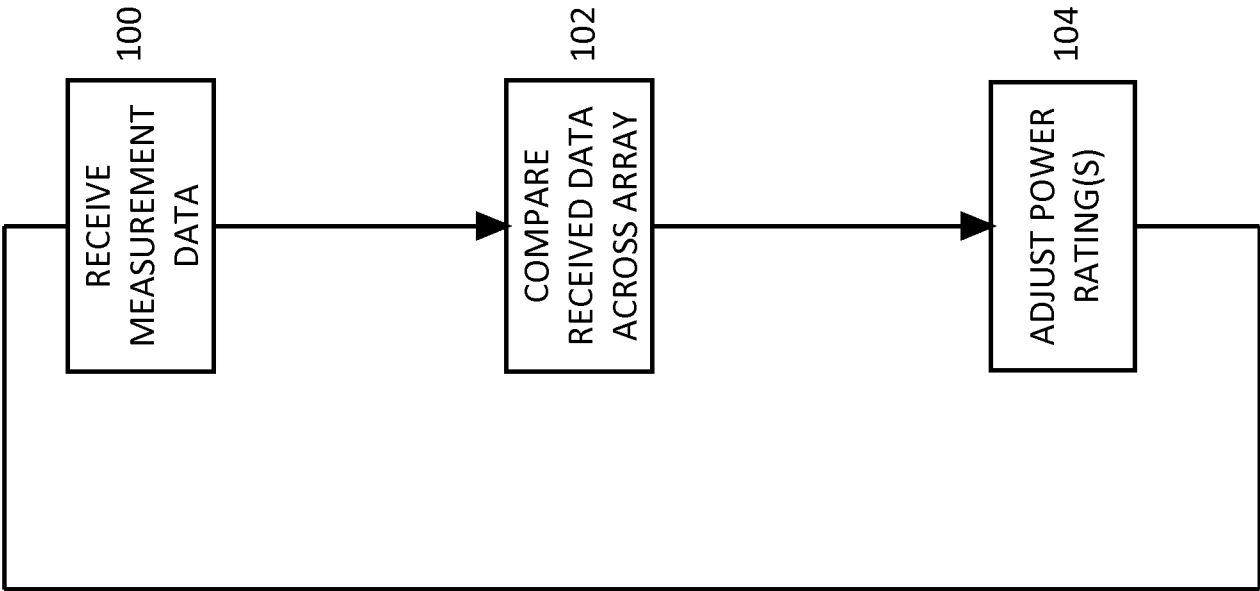


FIGURE 4

INTERNATIONAL SEARCH REPORT

International application No
PCT/GB2011/052398

A. CLASSIFICATION OF SUBJECT MATTER
INV. F03B5/00 F03B13/26 F03B17/06
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
F03B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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Y	page 6, line 23 - page 7, line 29; figures 1,2 page 9, lines 12-21 page 11, lines 28-31	2,4,5, 11,14,15
Y	----- US 2007/299548 A1 (WEITKAMP ROLAND [DE]) 27 December 2007 (2007-12-27) paragraphs [0045] - [0048]; figure 2	2,4,5, 11,14,15
A	----- US 2009/099702 A1 (VYAS PARAG [DE] ET AL) 16 April 2009 (2009-04-16) paragraphs [0021] - [0036]; figures 1-5 ----- -/-	1-15



Further documents are listed in the continuation of Box C.



See patent family annex.

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"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.
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INTERNATIONAL SEARCH REPORT

International application No

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C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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INTERNATIONAL SEARCH REPORT

Information on patent family members

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