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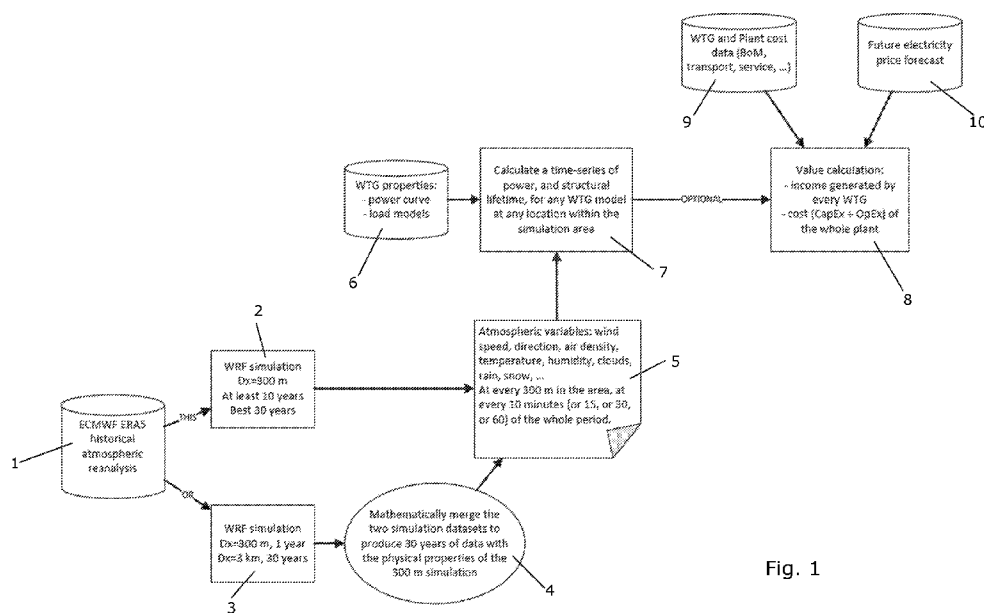


Fig. 1

(57) Abstract: A method for predicting performance of a planned wind power plant comprising a plurality of wind turbines (11) is disclosed. Historical atmospheric data (1) related to a region in which the site of the planned wind power plant is located, and information (12) regarding local terrain conditions at the site of the planned wind power plant, are obtained. Based on the historical atmospheric data (1) and the local terrain conditions (12), computer simulation (2, 3) of expected local wind and/or weather conditions expected at the site of the planned wind power plant, within a predefined future time period, is performed. Expected performance of the wind power plant is predicted (7, 13), based on the computer simulation (2, 3) and on information related to the wind turbines (11) of the planned wind power plant, within the predefined future time period.

RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, ME, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

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## A METHOD OF PREDICTING PERFORMANCE OF A PLANNED WIND POWER PLANT

### FIELD OF THE INVENTION

The present invention relates to a method for predicting performance of a planned wind power plant, i.e. of a wind power plant which has not yet been erected. The method according to the invention allows the performance of the  
5 planned wind power plant to be predicted in an accurate manner at low cost and with little effort, and without the need for a specific measurement campaign.

### BACKGROUND OF THE INVENTION

When planning a wind power plant, it is often desirable to predict how the wind  
10 power plant is expected to perform once it has been erected, e.g. in terms of power production of and/or loads on the wind turbines of the wind power plant. The expected performance may be a key feature for evaluating the feasibility of the planned wind power plant, e.g. in terms of return on investment.

The performance of a wind power plant depends strongly on local meteorological  
15 conditions, in particular local wind conditions, at the site of the wind power plant. Therefore, as part of the planning process, it is common to position measuring equipment, such as meteorological masts, at one or more selected positions within a candidate site for the planned wind power plant, in order to obtain information regarding the meteorological conditions, notably the wind  
20 conditions, prevailing at the candidate site.

However, meteorological conditions are likely to vary during the course of a year, as well as on a diurnal basis. Therefore, in order to obtain a representative picture of the meteorological conditions which are typically prevailing at the site, it is often necessary to perform measurements at the candidate site for a long  
25 period of time, most likely for at least one year. This prolongs the planning process and adds to the costs of planning the wind power plant. Furthermore, this cumbersome measuring process imposes an upper limit on how many

candidate sites it is possible to investigate, and there might therefore be a risk that the best suited site is not the one which is eventually selected.

## DESCRIPTION OF THE INVENTION

It is an object of embodiments of the invention to provide a method for  
5 predicting performance of a planned wind power plant which is faster, easier and less cumbersome than prior art methods.

The invention provides a method for predicting performance of a planned wind power plant, the planned wind power plant comprising a plurality of wind turbines to be arranged within a site of the planned wind power plant, the  
10 method comprising the steps of:

- obtaining historical atmospheric data related to a region in which the site of the planned wind power plant is located,
- obtaining information regarding local terrain conditions at the site of the planned wind power plant,
- 15 – based on the historical atmospheric data and the local terrain conditions, performing computer simulation of expected local wind and/or weather conditions expected at the site of the planned wind power plant, within a predefined future time period, and
- predicting expected performance of the wind power plant, based on the  
20 computer simulation and on information related to the wind turbines of the planned wind power plant, within the predefined future time period.

Thus, the method according to the invention is a method for predicting performance of a planned wind power plant. In the present context the term 'wind power plant' should be interpreted to mean a group of a plurality of wind  
25 turbines sharing infrastructure for power transmission, e.g. to a power grid. The wind turbines may be arranged at a geographical site. In the present context the term 'planned wind power plant' should be interpreted to mean a wind power

plant which has not yet been erected. Thus, the planned wind power plant comprises a plurality of wind turbines which are to be arranged, i.e. erected, within the site of the planned wind power plant.

The performance of the planned wind power plant being predicted may relate to the power or energy production of the wind turbines of the wind power plant, the loads on the wind turbines, the wear on the wind turbines, and/or any other suitable kind of performance which may have an impact on the return on investment of the owner of the wind power plant. This will be described in further detail below.

In the method according to the invention, historical atmospheric data is obtained. The obtained historical atmospheric data is related to a region in which the site of the planned wind power plant is located. The historical atmospheric data may relate to a very long previous period of time, preferably several years. Accordingly, the historical atmospheric data may be expected to reflect normal seasonal, diurnal, etc., variations in the atmospheric conditions prevailing in the region where the site of the planned wind power plant is located. Such data is readily available, e.g. from various meteorological services monitoring global weather conditions, e.g. by means of satellites, globally distributed weather stations, airplanes, weather balloons, etc. However, the spatial resolution of such atmospheric data is relatively low, and insufficient for providing detailed information regarding local wind and/or weather conditions at the site of the planned wind power plant, for instance at the hub height of the individual wind turbines of the planned wind power plant.

Furthermore, information regarding local terrain conditions at the site of the planned wind power plant is obtained. In the present context the term 'local terrain conditions' should be interpreted to mean conditions regarding the specific and detailed terrain at the site of the planned wind power plant. The information regarding local terrain conditions may, e.g., include information regarding physical features of the site of the planned wind power plant, such as vertical and horizontal dimensions of the land surface. This may, e.g., be expressed in terms of elevation, roughness, slope, orientation of terrain features, etc. The terrain features may comprise, but are not limited to, hills,

ridges, valleys, saddles, cliffs, urban areas, vegetation, coastlines, water bodies, etc.

Accordingly, the information regarding local terrain conditions is specifically linked to the site of the planned wind power plant, and it has a high spatial  
5 resolution.

Next, based on the historical atmospheric data and the local terrain conditions, computer simulation is performed of expected local wind and/or weather conditions expected at the site of the planned wind power plant, within a predefined future time period. This allows sufficiently detailed information  
10 regarding the local wind and/or weather conditions at the site of the planned wind power plant to be obtained.

As described above, the historical atmospheric data represents statistically reliable information regarding expected wind and/or weather conditions in the region in which the planned wind power plant is located, but with a relatively low  
15 spatial resolution. On the other hand, the information regarding local terrain conditions represents local conditions prevailing at the site of the planned wind power plant, but without reflecting wind and/or weather conditions. Thus, the computer simulation being based on the historical atmospheric data as well as on the local terrain conditions, takes the statistically reliable, and physically  
20 consistent, wind and/or weather conditions as well as the local topographic conditions prevailing at the site of the wind power plant into account.

Accordingly, the resulting simulated expected wind and/or weather conditions may be assumed to accurately reflect local wind and/or weather conditions throughout the site of the planned wind power plant.

25 Finally, expected performance of the wind power plant is predicted, based on the computer simulation and on information related to the wind turbines of the planned wind power plant, within the predefined future time period. As described above, the computer simulation provides accurate information regarding expected local wind and/or weather conditions throughout the site of the  
30 planned wind power plant and within the predefined future time period. Combining this with relevant information regarding the wind turbines of the

planned wind power plant, it can be predicted how the wind turbines of the planned wind power plant may be expected to operate when subjected to the expected wind and/or weather conditions prevailing at their exact planned positions within the site of the planned wind power plant, and thereby the performance of the wind turbines, and accordingly of the planned wind power plant, can be predicted.

Due to the mathematical simulation, the expected performance of the planned wind power plant is predicted without the need for performing local weather and/or wind measurements at the site of the planned wind power plant. Thus, it is not necessary to await lengthy measurement periods before being able to evaluate whether or not a given candidate site is suitable. This significantly reduces the costs of investigating a candidate site and makes it feasible to investigate a larger number of candidate sites before selecting a site and erecting the wind power plant. Thereby the likelihood of selected the most optimal site for the planned wind power plant is increased.

The method according to the invention may further comprise the step of erecting the planned wind power plant at the site.

The information related to the wind turbines of the planned wind power plant may comprise expected positions of the wind turbines within the site of the planned wind power plant. According to this embodiment, the expected performance of a given wind turbine is predicted based on expected wind and/or weather conditions which are expected to prevail at the exact position within the site of the planned wind power plant where the wind turbine is supposed to be erected. This provides accurate prediction of performance of that specific wind turbine under the conditions which that specific wind turbine is expected to be subjected to.

Alternatively or additionally, the information related to the wind turbines of the planned wind power plant may comprise structural specifications and/or power curves of the wind turbines. Such information regarding the wind turbines reflects how the wind turbines react to certain wind and/or weather conditions, and it is therefore relevant with regard to how the wind turbines perform under

the expected wind and/or weather conditions. For instance, an expected power production may be derived based on the power curves, and expected loads or wear on the wind turbines may be derived based on the structural specifications.

The structural specifications of the wind turbines may, e.g., include type and/or model of the wind turbines, type and/or model of various components of the wind turbines, material thickness, hub height, tower height, length of the wind turbine blades, rotor diameter, and/or any other suitable and relevant structural specification.

The step of predicting expected performance of the wind power plant may comprise predicting expected power output of and/or expected loads on the wind turbines of the planned wind power plant within the predefined future time period.

The expected power output of the wind turbines of the wind power plant provides a measure for the expected production, and thereby for the expected income, of the wind power plant, during the predefined future time period. The expected loads on the wind turbines of the wind power plant provides a measure for expected wear, need for maintenance, need for replacement of components, etc., of the wind turbines, and thereby a measure for expected costs of operating the wind power plant, during the predefined future time period.

Accordingly, the expected power output as well as the expected loads on the wind turbines of the planned wind power plant is relevant with regard to expected net revenue of the planned wind power plant, during the predefined future time period. Accordingly, the expected power output and/or the expected load form relevant input with regard to evaluating whether or not it will be feasible to erect the planned wind power plant.

The predefined future time period may have a duration of at least one year. For instance, the predefined future time period may cover an expected lifetime of the planned wind power plant. According to this embodiment, the predicted performance of the planned wind power plant relates to at least one year of operation, possibly to the entire expected lifetime of the planned wind power plant. The expected lifetime of a wind power plant is normally 20-25 years.

The historical atmospheric data may comprise high resolution, short term data as well as low resolution, long term data. According to this embodiment, the combination of the high resolution, short term data and the low resolution, long term data may be used for estimating high (temporal) resolution, long term behaviour of wind and/or weather within the region in which the site of the planned wind power plant is located. This, in turn, allows accurate prediction of the local wind and/or weather conditions at the site of the planned wind power plant, by means of the computer simulation, and when combined with the information regarding local terrain conditions at the site of the planned wind power plant. In other words, the resulting simulation will have the precision of the short term data and the duration of the long term data.

For instance, the short term data may cover 1 year, whereas the long term data may cover an expected lifespan of the planned wind power plant, such as 20 or 30 years.

The step of performing computer simulation may further take expected future changes in climate conditions into account. It is known that climate conditions are changing, and basing the computer simulation on historical atmospheric data may therefore lead to an inaccurate prediction of the performance of the wind power plant several years into the future. Thus, according to this embodiment, the historical atmospheric data is adjusted or modified to take into account expected future changes in climate conditions, within the region in which the site of the planned wind power plant is located. This increases the accuracy of the resulting prediction of the expected performance of the planned wind power plant. Expected changes in climate conditions could, e.g., include changes in temperature, turbulence conditions, wind speeds, humidity, air density, etc.

The step of performing computer simulation may further take expected local turbulence conditions at the site of the planned wind power plant into account. The local turbulence conditions may be at least partly caused by various terrain conditions or obstacles within the site of the planned wind power plant, and/or by wake effects generated by the wind turbines of the planned wind power plant. Local turbulence conditions are particularly relevant with regards to loads on the wind turbines, and accordingly this is at least relevant with respect to predicting

performance of the planned wind power plant in terms of expected loads and/or wear on the wind turbines of the planned wind power plant.

The step of performing computer simulation may be performed without input from local measurements of wind and/or weather conditions. As described  
5 above, it is an advantage of the method according to the invention that accurate predictions of the expected performance of the planned wind power plant can be obtained without requiring local, and often lengthy, measurements of wind and/or weather conditions, at the site of the planned wind power plant.

According to one embodiment, the method may further comprise the step of  
10 modifying an output of the computer simulation based on measured data which has been obtained for other purposes than planning of the wind farm. For instance, the measured data may have been obtained at least 20 km from the site of the planned wind power plant. According to this embodiment, the computer simulation may be refined by including measured data, e.g. measured  
15 wind and/or weather data, which has been obtained at a location near the site of the planned wind power plant, and which may therefore be expected to approximately represent wind and/or weather conditions at the site of the planned wind power plant. The measured data may, e.g., be obtained from equipment which is already applied for other purposes, e.g. a general weather  
20 station, wind turbines and/or meteorological masts forming part of an operating nearby wind power plant, etc.

#### BRIEF DESCRIPTION OF THE DRAWINGS

The invention will now be described in further detail with reference to the accompanying drawings in which

25 Fig. 1 is a block diagram illustrating a method according to an embodiment of the invention, and

Figs. 2-6 illustrate various embodiments of the invention.

## DETAILED DESCRIPTION OF THE DRAWINGS

Fig. 1 is a block diagram illustrating a method for predicting performance of a planned wind power plant according to an embodiment of the invention.

Historical atmospheric data 1 is obtained from various relevant sources, such as global weather services. The historical atmospheric data 1 is related to a region in which the site of the planned wind power plant is located, and the historical data 1 has a relatively low spatial resolution, i.e. the historical atmospheric data 1 represents long term and large scale data in the region where the planned wind power plant is located. However, the historical atmospheric data 1 may be vast, and it can be assumed to represent statistically representative wind and/or weather conditions within the region where the planned wind power plant is located, e.g. reflecting seasonal variations, diurnal variations, average years, outlier years, etc.

The historical atmospheric data 1 is applied for performing either a first computer simulation 2, or a pair of second computer simulations 3, in order to obtain information regarding expected wind and/or weather conditions throughout the site of the planned wind power plant. The first computer simulation 2 produces high resolution, long term historical atmospheric data, and the pair of second computer simulations 3 produce low resolution, long term historical atmospheric data ( $D_x=3$  km, 30 years) and high resolution, short term historical atmospheric data ( $D_x=300$  m, 1 year). Furthermore, the first computer simulation 2 as well as the pair of second computer simulations 3 takes information regarding local terrain conditions at the site of the planned wind power plant into account. Accordingly, by means of the computer simulations 2, 3, the historical atmospheric data 1, which is large scale and non-specific for the site of the planned wind power plant, is combined with specific and local information regarding the terrain conditions at the site of the planned wind power plant.

In the pair of second computer simulations 3 the high resolution, short term data and the low resolution, long term data are merged 4, and the result is a prediction 5 of expected local wind and/or weather conditions across the site of the planned wind power plant, within a predefined future time period. In the

case that only the first simulation 2 is performed, the prediction 5 is obtained without the need for merging 4.

Based on the prediction 5 of expected local wind and/or weather conditions and relevant information regarding properties 6 of the wind turbines of the planned wind power plant, performance 7 of the planned wind power plant is predicted, in the form of time series of power production and structural lifetime of the wind turbines. The properties 6 of the wind turbines may, e.g., include power curves and/or structural specifications of the wind turbines.

Based on the predicted performance 7 of the planned wind power plant, a value calculation 8 is performed. The value calculation 8 further takes costs 9 of establishing the planned wind power plant and expected future electricity price 10 into account. The value calculation 8 provides a relevant foundation for deciding whether or not it is feasible to erect the planned wind power plant.

Fig. 2 illustrates a method for predicting performance of a planned wind power plant according to a first embodiment of the invention. The method illustrated in Fig. 2 may, e.g., include the steps illustrated in Fig. 1. A computer simulation 2 predicts expected wind and/or weather conditions across the site of the planned wind power plant, based on global, large scale historical atmospheric data related to the region in which the planned wind power plant is located, and based on information regarding terrain conditions at the site of the planned wind power plant. Based on the predicted expected wind and/or weather conditions and on information related to the wind turbines 11 of the planned wind power plant, the computer simulation 2 further predicts the performance of the wind turbines 11, during a predefined future time period, in the form of expected power output of and/or expected loads on the wind turbines 11 during the predefined future time period.

Fig. 3 illustrates a method for predicting performance of a planned wind power plant according to a second embodiment of the invention. The method illustrated in Fig. 3 is very similar to the method illustrated in Fig. 2, and it will therefore not be described in detail here.

In the method of Fig. 3, one of the pair of the second computer simulations 3 produces high resolution, short term historical atmospheric data, and another of the pair of the second computer simulations 3 produces low resolution, long term historical atmospheric data, similar to the situation described above with reference to Fig. 1. The results of the two simulations 3 are merged 7 to produce high resolution, long term historical atmospheric data. For each wind turbine 11 of the planned wind power plant, performance of the wind turbine 11 is then predicted 7, based on the output of each of the simulations 2, 3, and on relevant information regarding the respective wind turbines 11, e.g. in the form of power curves and/or structural specifications.

The historical atmospheric data applied in the first simulation 2 and/or in the pair of second simulations 3 may be applied directly. Alternatively or additionally, expected future changes in climate conditions may be taken into account in one or both of the simulations 2, 3.

Fig. 4 illustrates a method for predicting performance of a planned wind power plant according to a third embodiment of the invention. The method illustrated in Fig. 4 is very similar to the method illustrated in Fig. 3, and it will therefore not be described in detail here. However, in the method illustrated in Fig. 4, the merging and prediction 7 of performance of the wind turbines 11 is performed by a single algorithm, rather than applying separate algorithms for each of the wind turbines 11. This may result in predictions 7 which are more spatially and temporally consistent, and this may be an advantage in some situations.

Fig. 5 illustrates a method for predicting performance of a planned wind power plant according to a fourth embodiment of the invention. The method illustrated in Fig. 5 is very similar to the method illustrated in Fig. 4, and it will therefore not be described in detail here.

In the method illustrated in Fig. 5, information 12 regarding local terrain conditions at the site of the planned wind power plant is further obtained. The information 12 regarding local terrain conditions and the output of the first computer simulation 2 is applied for predicting 13 expected turbulence conditions prevailing at the site of the planned wind power plant, and, based

thereon, expected load impact and expected lifetime of the wind turbines 11 of the planned wind power plant is predicted.

Fig. 6 illustrates a method for predicting performance of a planned wind power plant according to a fifth embodiment of the invention. The method illustrated in  
5 Fig. 6 is very similar to the method illustrated in Fig. 5, and it will therefore not be described in detail here. However, in the method illustrated in Fig. 6, the prediction 13 of turbulence conditions, loads and expected lifetime is further based on the output of the pair of second computer simulations 3, including the low resolution, long term data as well as the high resolution, short term data.

## CLAIMS

1. A method for predicting performance of a planned wind power plant, the planned wind power plant comprising a plurality of wind turbines (11) to be arranged within a site of the planned wind power plant, the method comprising  
5 the steps of:

- obtaining historical atmospheric data (1) related to a region in which the site of the planned wind power plant is located,
- obtaining information (12) regarding local terrain conditions at the site of the planned wind power plant,
- 10 – based on the historical atmospheric data (1) and the local terrain conditions (12), performing computer simulation (2, 3) of expected local wind and/or weather conditions expected at the site of the planned wind power plant, within a predefined future time period, and
- predicting (7, 13) expected performance of the wind power plant, based  
15 on the computer simulation (2, 3) and on information related to the wind turbines (11) of the planned wind power plant, within the predefined future time period.

2. A method according to claim 1, wherein the information related to the wind turbines (11) of the planned wind power plant comprises expected positions of  
20 the wind turbines (11) within the site of the planned wind power plant.

3. A method according to claim 1 or 2, wherein the information related to the wind turbines (11) of the planned wind power plant comprises structural specifications and/or power curves of the wind turbines (11).

4. A method according to any of the preceding claims, wherein the step of  
25 predicting (7, 13) expected performance of the wind power plant comprises predicting expected power output of and/or expected loads on the wind turbines (11) of the planned wind power plant within the predefined future time period.

5. A method according to any of the preceding claims, wherein the predefined future time period has a duration of at least one year.

6. A method according to claim 5, wherein the predefined future time period covers an expected lifetime of the planned wind power plant.

5 7. A method according to any of the preceding claims, wherein the historical atmospheric data comprises high resolution, short term data as well as low resolution, long term data.

8. A method according to any of the preceding claims, wherein the step of performing computer simulation (2, 3) further takes expected future changes in  
10 climate conditions into account.

9. A method according to any of the preceding claims, wherein the step of performing computer simulation (2, 3) further takes expected local turbulence conditions at the site of the planned wind power plant into account.

10. A method according to any of the preceding claims, wherein the step of  
15 performing computer simulation (2, 3) is performed without input from local measurements of wind and/or weather conditions.

11. A method according to any of the preceding claims, further comprising the step of modifying an output of the computer simulation (2, 3) based on measured data obtained at least 20 km from the site of the planned wind power  
20 plant.

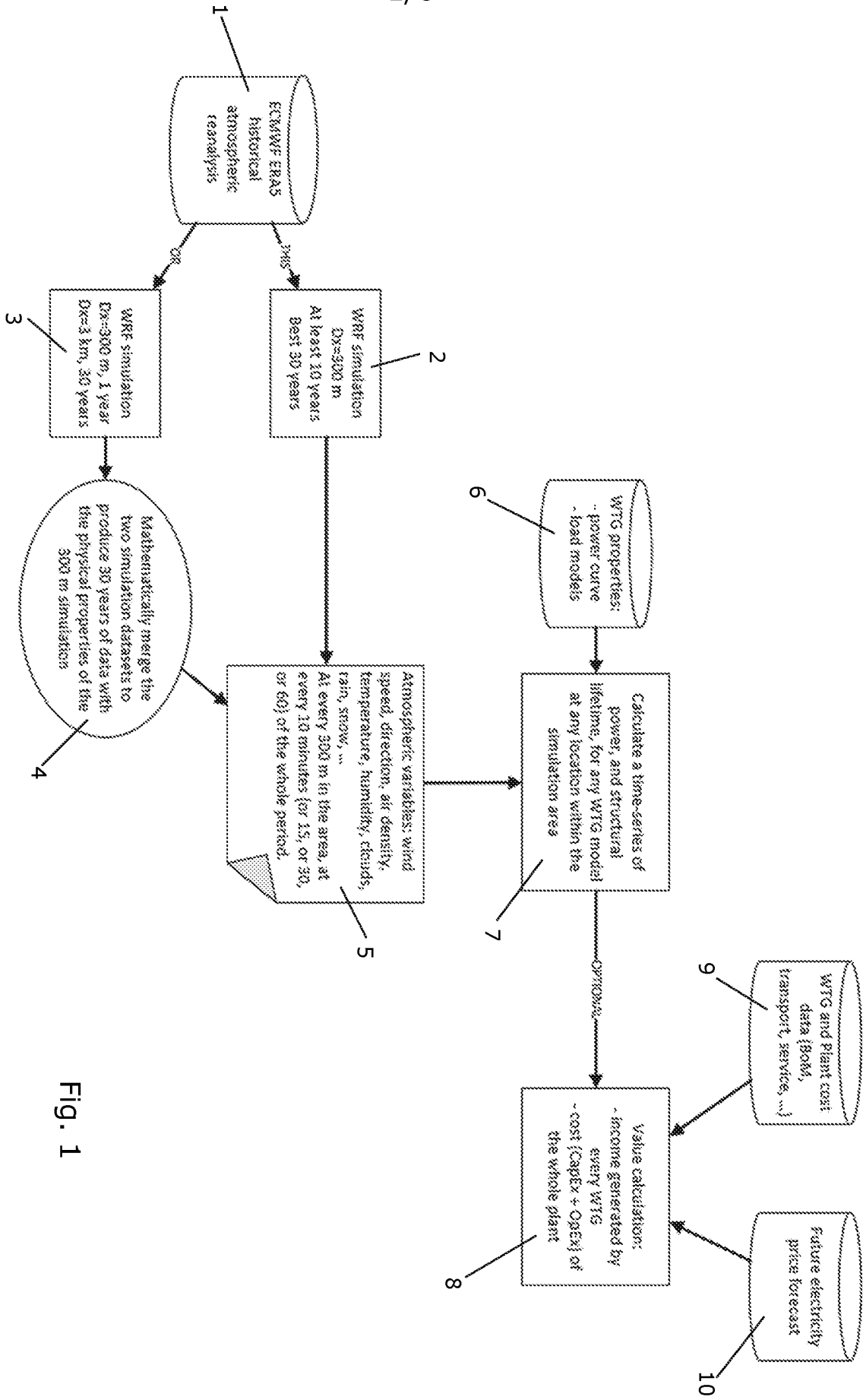


Fig. 1

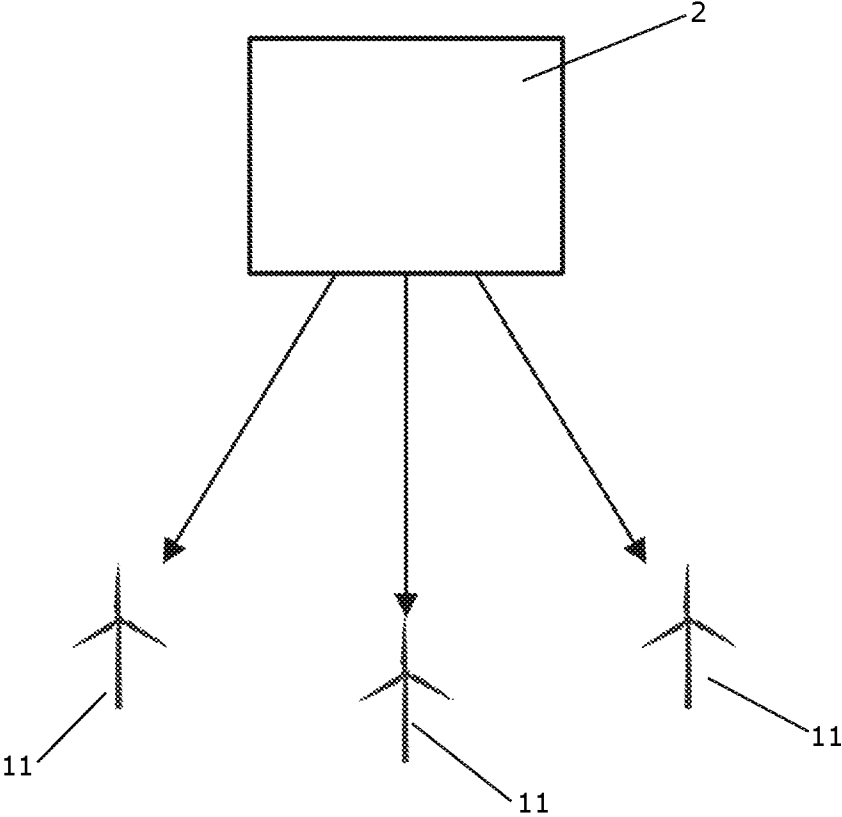


Fig. 2

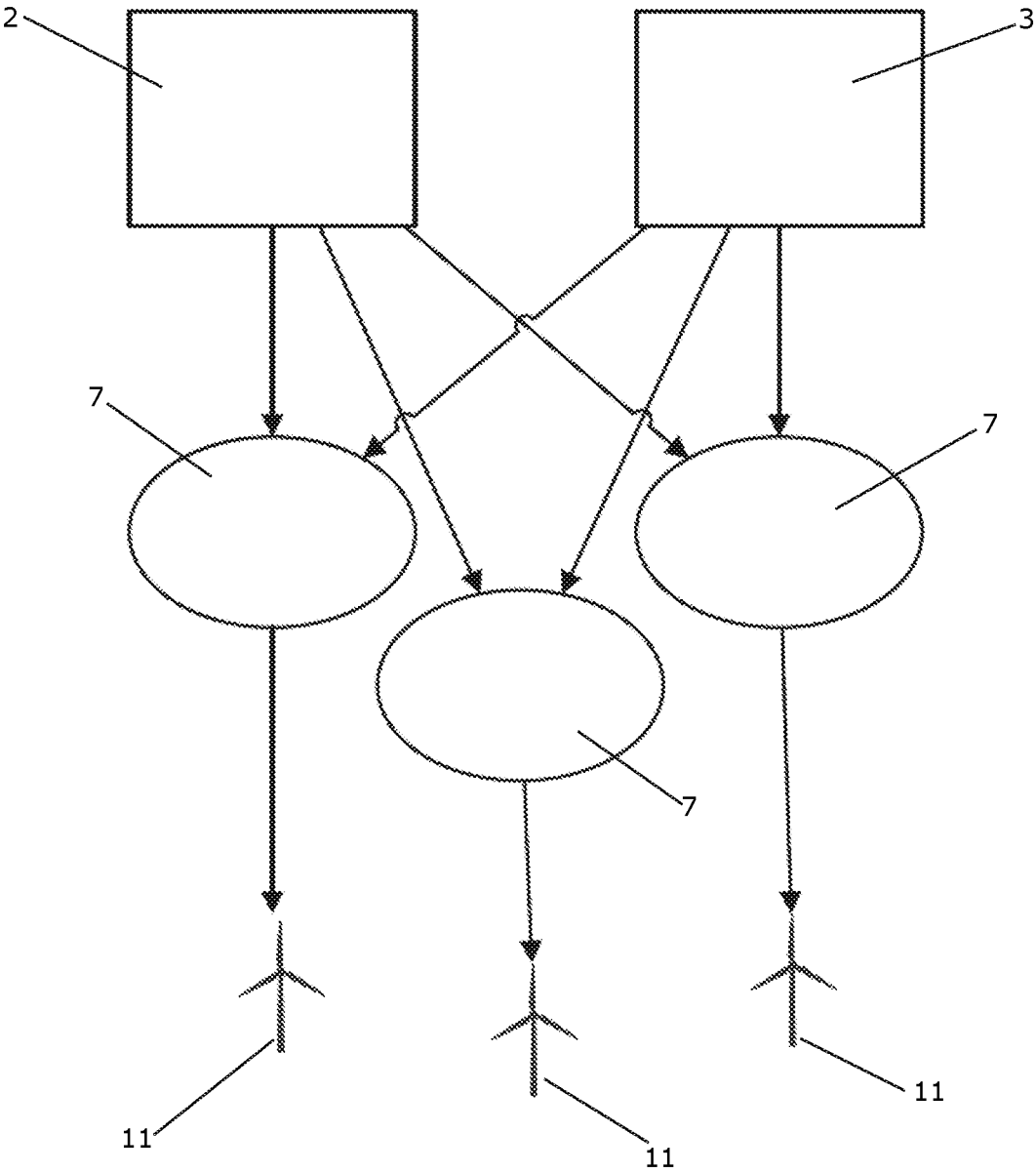


Fig. 3

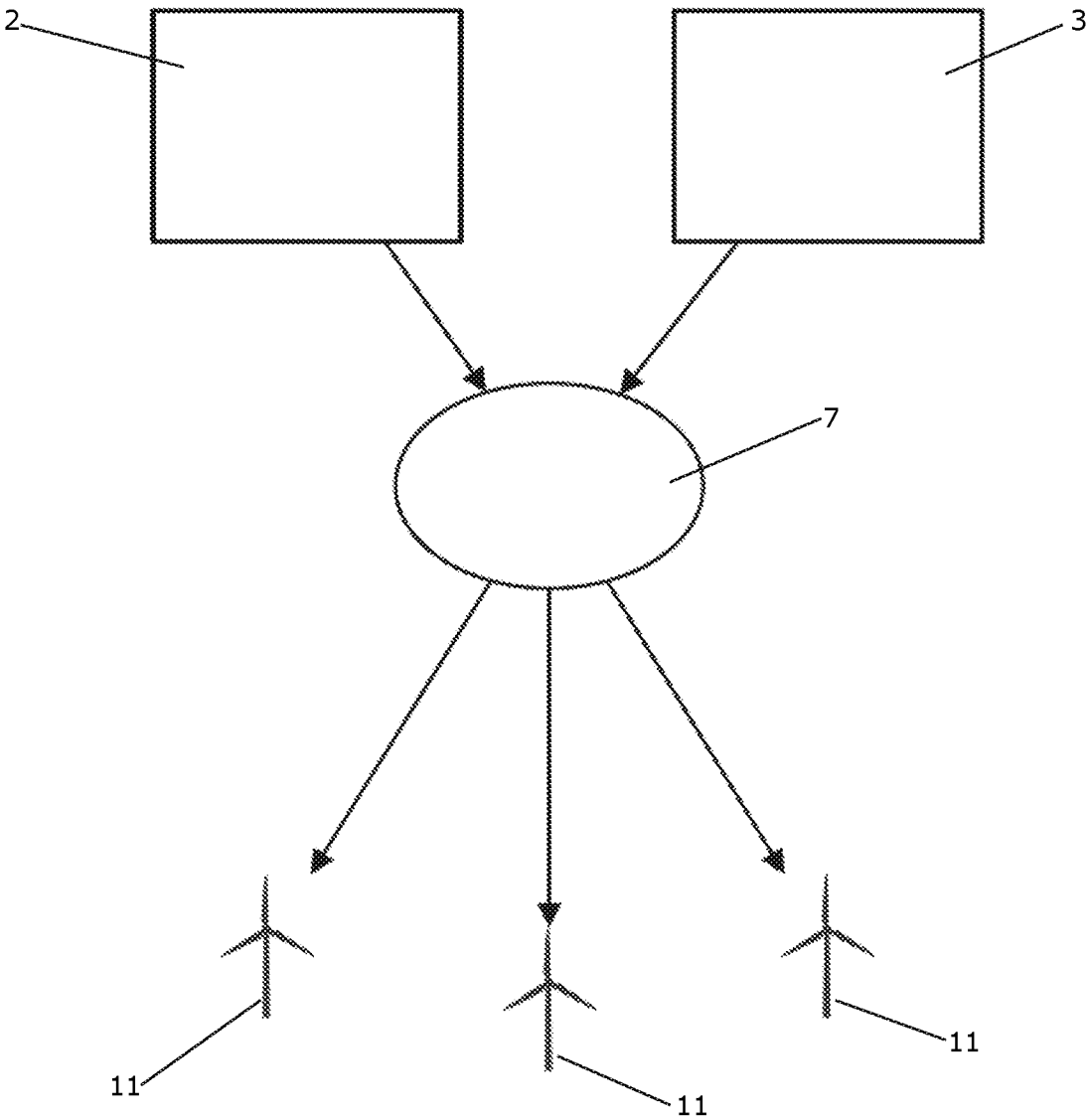


Fig. 4

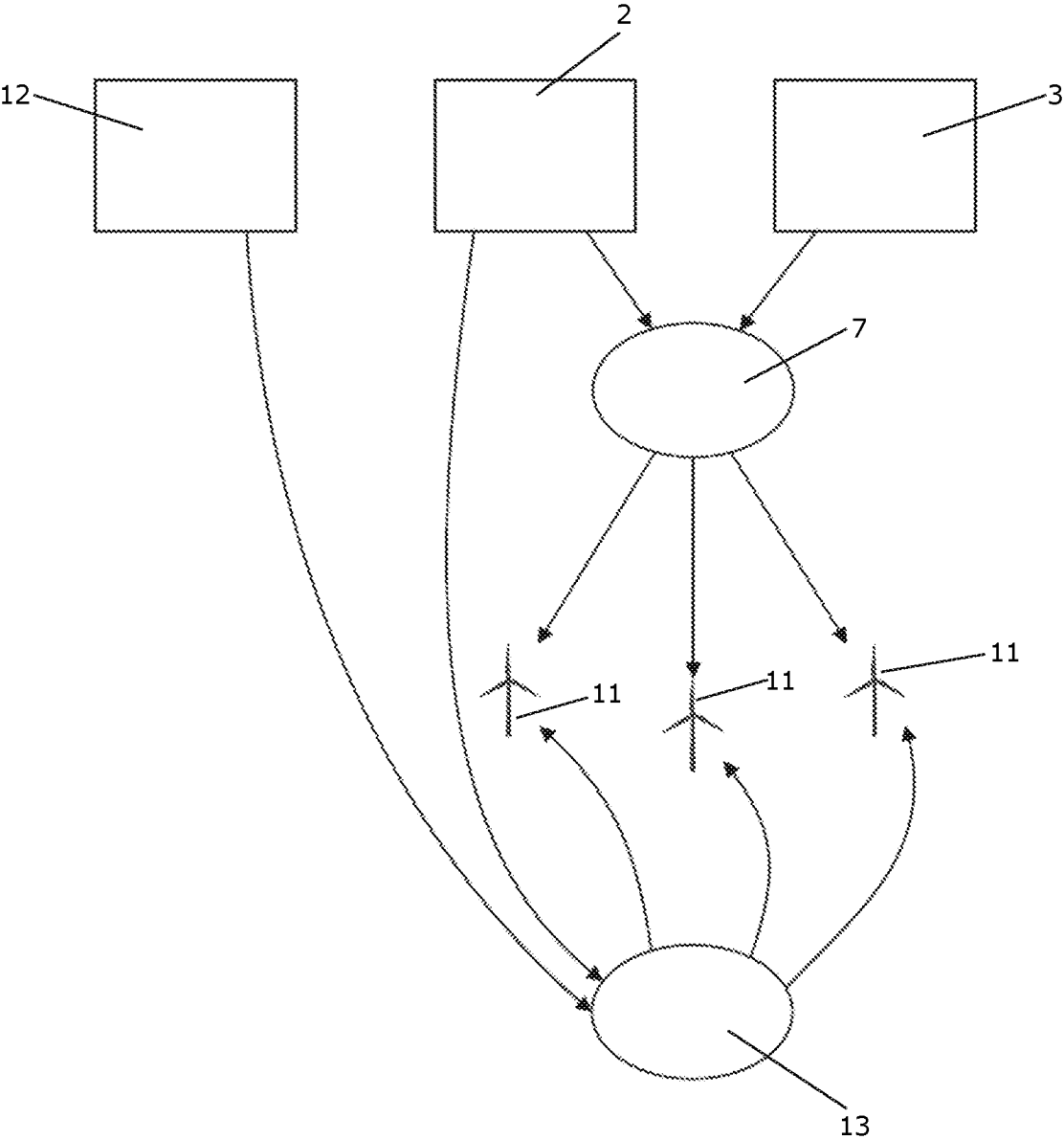


Fig. 5

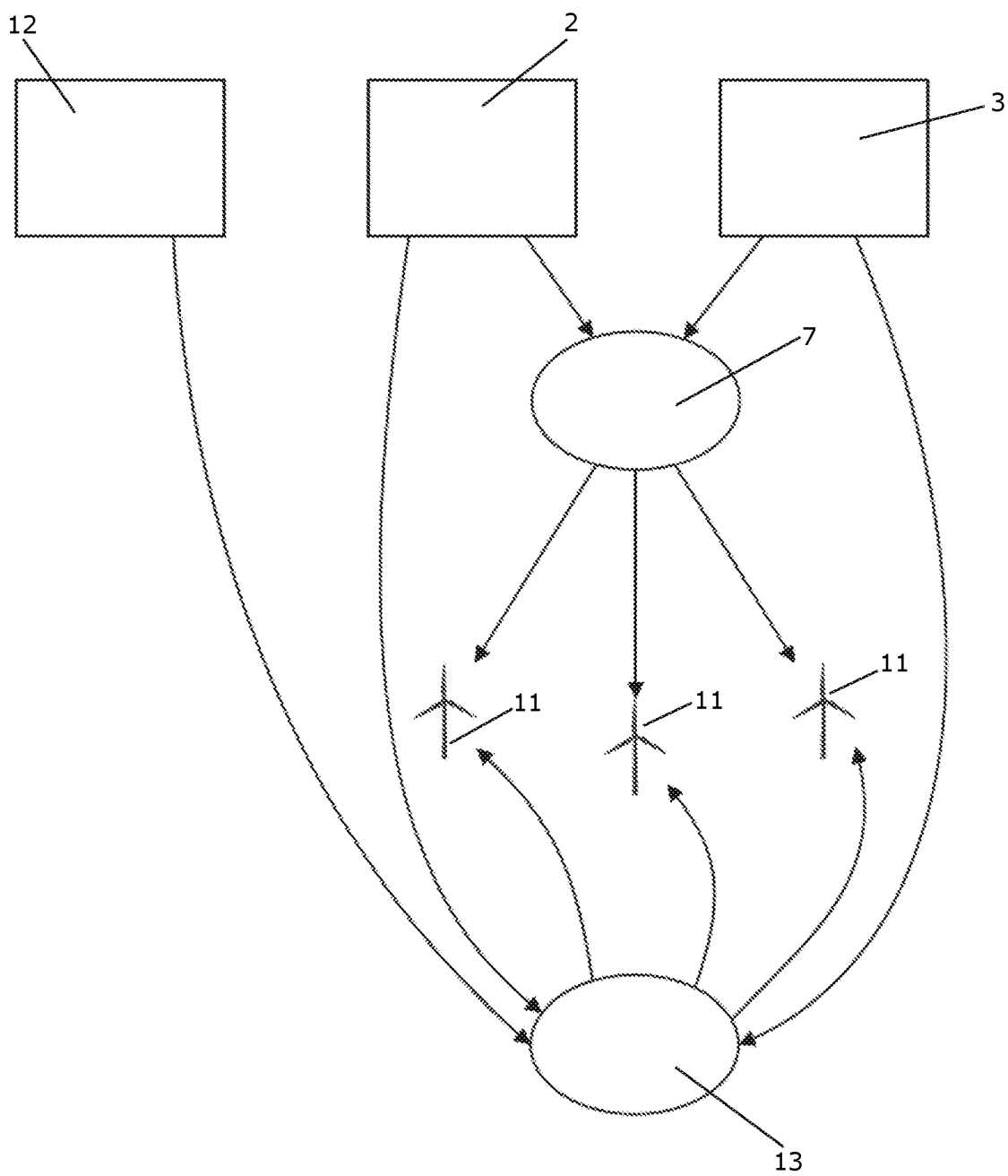


Fig. 6

## INTERNATIONAL SEARCH REPORT

International application No  
PCT/DK2024/050132

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| <b>A. CLASSIFICATION OF SUBJECT MATTER</b><br>INV. F03D7/04 F03D17/00<br>ADD.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                                                                                                                                                                                                                             |                                                                      |
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| <b>B. FIELDS SEARCHED</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |                                                                                                                                                                                                                                             |                                                                      |
| Minimum documentation searched (classification system followed by classification symbols)<br>F03D                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |                                                                                                                                                                                                                                             |                                                                      |
| 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 practicable, search terms used)<br>EPO-Internal                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |                                                                                                                                                                                                                                             |                                                                      |
| <b>C. DOCUMENTS CONSIDERED TO BE RELEVANT</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                                                                                                                                                                                                                             |                                                                      |
| Category*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | Citation of document, with indication, where appropriate, of the relevant passages                                                                                                                                                          | Relevant to claim No.                                                |
| X                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | US 7 403 854 B1 (HURLEY BRIAN [IE] ET AL)<br>22 July 2008 (2008-07-22)<br>paragraph [0001] - paragraph [0003]<br>paragraph [0050] - paragraph [0052]<br>paragraph [0025] - paragraph [0030]<br>paragraph [0036] - paragraph [0037]<br>----- | 1-4,9,10                                                             |
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