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**Description**

The invention relates to a method and an arrangement for measurement of a wind energy installation. In the method, associated measurement sets for a plurality of parameter sets of the wind energy installation are recorded, wherein the measurement sets comprise successive measurement vectors in time. The arrangement comprises a measurement device for recording successive measurement vectors in time, a parameter memory for storing parameter sets, a control module for adjusting the wind energy installation according to the parameter sets, and a data memory which is designed to store the measurement vectors in measurement sets and to associate the measurement sets with the parameter sets.

Wind energy installations in which electrical energy is produced via a rotor and a generator are widely used. The operating state of a wind energy installation is governed by a multiplicity of parameters. Merely by way of example, the pitch angle of the rotor blades, the rotation speed characteristic of the generator and regulator settings may be mentioned as parameters here.

Information relating to the system characteristics of the wind energy installation is required both in order to ensure optimum operation and in order to verify that the wind energy installation is being operated in accordance with the specifications. The system characteristics are measured for this purpose with various parameter settings and in various wind conditions, see, for example, DE19934415. By way of example, the power output, the noise behaviour or the oscillation behaviour can be measured as system characteristics.

The system characteristics are varied between light and strong winds, between gusts and uniform winds, etc. For this reason, comprehensive measurement of the system characteristics includes measurements in many different wind conditions. One

problem is that the wind conditions cannot be influenced and that, in particular, the desired wind conditions do not occur in a rapid sequence.

5    Until now, when measuring wind energy installations, it has been normal practice to set the parameters of the wind energy installation to specific values and to maintain these parameter settings until the measurement for this parameter set has been completed, that is to say until all the various  
10    wind conditions have occurred successively. The wind energy installation is then set to a different parameter set, and the system characteristics of this parameter set are measured completely. The measurement is a tedious process, even for a single parameter set, because of the dependency on the wind  
15    conditions. It is extremely time-consuming to measure a wind energy installation wherein the aim is to measure a plurality of parameter sets successively.

A further disadvantage of the previous method is that the  
20    measurements recorded for different parameter sets cannot directly be compared. It is admittedly possible to wait for individual parameters of the wind, such as the wind strength and wind direction, to occur again, for measuring the next parameter set. However, the measurement results are dependent  
25    on further parameters of the wind, such as the air density, the turbulence and the wind gradient. This results in difficulties when comparing measurement results.

The invention is based on the object of proposing a method and  
30    an apparatus which reduce the time required for measurement of the wind energy installation, with the same or a better measurement quality.

The object is achieved by the features of the independent  
35    claims. In the case of a method according to the precharacterizing clause of Claim 1, cyclic changes are made between the parameter sets, and measurement vectors are recorded for each parameter set in more than one cycle. In the

case of an arrangement according to the precharacterizing clause of Claim 17, the control module is designed to select one parameter set from the parameter sets in cycles and, after each selection, to activate the measurement set associated with the selected parameter set in the data memory. Advantageous embodiments are specified in each of the dependent claims.

First of all, a number of terms will be defined.

The parameters of a wind energy installation are the variables which characterize the operating state. In particular, the parameters comprise all variables which can be preset or can be adjusted automatically. By way of example, these are the blade pitch angle, the torque, the rotation speed, the regulator settings, the gain factors as well as settings for active or passive measures for oscillation damping. All the parameters in one parameter set have a fixed value or have a fixed functional relationship (characteristic).

A measurement vector contains the data relating to the wind energy installation recorded in a single measurement interval. While the data is being recorded for one measurement vector, the parameter set of the wind energy installation remains constant. One measurement vector may comprise a plurality of data items recorded in the time period. However, the term measurement vector is also used when it contains only a single value. A single value such as this may, for example, be an average value over a measurement interval.

A measurement set comprises a plurality of measurement vectors. The measurement vectors in a measurement set are distinguished by containing data which has been recorded using the same parameter set. Each measurement set is therefore associated with one specific parameter set. Since the measurement vectors are recorded in different wind conditions, they are successive in time.

The expression activation of a measurement set in a data memory is used when a single measurement set is selected from a plurality of measurement sets, and the next measurement data items to be stored are associated with the selected measurement set.

In contrast to the previously normal procedure, the measurement vectors of a measurement set are no longer all recorded in a direct time sequence, but a change is made between the parameter sets, in cycles. The expression a change in cycles is used when the parameter sets are selected at least twice during the measurement process. There is therefore no need for each cycle to include each parameter set, and there is likewise no need for the parameter sets to follow one another in the same sequence within the cycles.

Since changes are made between the parameter sets and the associated measurement sets in cycles, in each case before all the measurement vectors of the relevant measurement set have been recorded, this means that the various parameter sets are measured effectively in parallel. The expression complete parallelity is, however, not used, because it is never possible to select two parameter sets at one time. However, the processing of one parameter set and therefore measurement set is interrupted before all the measurement vectors in the measurement set have been recorded, and a change is made to a next parameter set and measurement set. This results in the parameter sets and measurement sets being effectively processed in parallel.

In comparison to sequential processing of the parameter sets and measurement sets, the measurement effectively in parallel according to the invention offers a considerable time saving, because there is no need to wait once again for specific wind conditions to occur for each parameter set. Furthermore, this results in better comparability of the measured values in different parameter sets, because the wind conditions remain largely constant within the short time which is taken to

change between two parameter sets. This means better quality of comparability of the measurement results.

The method is used to measure at least two parameter sets.

5 However, the time saving can be increased by measuring more than two parameter sets.

Each measurement vector preferably comprises data from a measurement interval whose length is between 1 and 15 minutes,

10 and furthermore preferably between 8 and 12 minutes.

After a change in the parameter set, the wind energy installation can be subject to non-stationary transient effects in a transitional phase. In order to prevent the

15 measurement from being corrupted, the method advantageously waits for non-stationary transient effects to first of all decay after a change in the parameter set and before the next measurement vector is recorded. If the decay time duration is known, then the length of the transitional phase can be preset

20 to be fixed, corresponding to the known duration.

In particular, the fixed length of the transitional phase to be set can be made dependent on the variable to be measured.

For example, after adjusting the pitch angle of the rotor blades, it will take between 20 seconds and 1 minute for the rotor to assume a steady state. As soon as the steady state has occurred, data, for example relating to the power output of the generator, can be recorded. However, if a change in

parameters influences the oscillation behaviour of the wind energy installation, it can take up to 10 minutes for the non-stationary transient effects to decay. Particularly in the case of off-shore wind energy installations, which are additionally affected by sea waves, it can take a very long time for a new steady oscillation state to occur. It is

35 therefore necessary to wait for a considerably longer transitional phase before recording data relating to the oscillation behaviour after a parameter change.

Instead of using transitional phases of predetermined length, it may also be advantageous to determine the duration of the transitional phase dynamically, and to measure whether the transient effects have decayed after each parameter change.

5 The process of recording the next measurement vector is started only after the end of the decay.

Particularly in the case of short transitional phases, the parameter set can be changed after recording each measurement  
10 vector. If the transitional phases are long, it may be possible to first of all record a plurality of measurement vectors before changing the parameter set.

The measurement vectors advantageously contain data relating  
15 to the power output, the network compatibility, the noise emission and/or the oscillation behaviour of the wind energy installation. It is also possible to record data relating to further loads and stresses. The arrangement preferably comprises detectors for all these variables, in particular  
20 detectors for the oscillation behaviour and/or the noise emission of the wind energy installation.

Furthermore, the measurement vectors may also comprise data relating to the wind conditions, in particular the wind  
25 direction and the wind strength. These data items can be obtained with the aid of an anemometer which is arranged on the wind energy installation. The data obtained using this anemometer may, however, be inaccurate, for example because the anemometer is located in the wake of the rotor. In order  
30 to avoid these inaccuracies, a measurement mast equipped with wind sensors can be installed in front of or alongside the wind energy installation. However, this is costly. It is therefore advantageous to record the data relating to the wind conditions on an adjacent wind energy installation. This can  
35 either be done by using an anemometer arranged on the adjacent wind energy installation, or by drawing conclusions about the wind conditions from the power output of the rotor. In particular, the adjacent wind energy installation can be

arranged adjacent to one side in the wind direction, in order that the two wind energy installations are not influenced by the mutual wakes. This advantageous effect can also be achieved by arranging the adjacent wind energy installation at a sufficient distance in the wind direction from the wind energy installation to be measured.

The arrangement may have a selection unit for association of an adjacent wind energy installation as an anemometer. In particular, this can be designed to allocate a wind energy installation which is adjacent laterally in the wind direction.

In order to measure the wind energy installation, it may be necessary to match the installation to the prevailing location conditions. The measured data and the location-specific wind distribution can be used to find parameter sets which promise a high annual energy yield. For this purpose, it is desirable to have a multiplicity of data items, and to compare these items with one another. This can be simplified by recording measurement matrices instead of measurement vectors. Each measurement set then comprises a plurality of measurement matrices, instead of a plurality of measurement vectors. By way of example, the power versus the wind speed and the turbulence value can be recorded in a measurement matrix such as this (so-called capture matrix). A plurality of initial conditions must occur in combination for each individual measurement vector within the measurement matrix. Since some of these combinations are less common than others, a priority can be defined, on the basis of which the measurement matrix is completed. The sequence of data recording may also be prioritized independently of the measurement matrix. For example, the standard power curve may have a higher priority than the noise emission and the network compatibility.

Parameters which are particularly suitable for location-specific matching are, for example, the blade pitch angle in the partial load range, rotation speed characteristics for

reduced-noise operation, or else converter parameters for the network behaviour. The latter can also be measured in very short measurement intervals (considerably less than 2 minutes). Furthermore, it is also possible to vary system parameters which describe mechanical characteristics, for example the mass of components that are subject to oscillation and which influence the natural frequencies of the system. By way of example, these masses can be influenced by ballast tanks which are flooded with water.

In the case of the measurements for determining optimum operating states, importance is placed on keeping the costs low. The installation can be designed particularly advantageously by equipping it with a single memory module which comprises both the parameter memory and the data memory. It is likewise cost-effective to arrange the control module within the wind energy installation.

In addition to determining optimum operating states, the measurements can also be carried out by experts. Expert measurements are carried out by independent third parties, for example to determine whether the wind energy installation is operating in accordance with the specifications. Expert measurements are subject to stringent requirements relating to neutrality and manipulation security. In particular, intentional or unintentional influencing of the measurement results by selecting better parameters must be precluded. A control module separate from the wind energy installation can be provided for this purpose, which is used to change between parameter sets. The control module can be arranged with the expert, and can thus be protected against any influence by the operator of the wind energy installation. The expert can then, for example, change in any desired sequence between high-yield and low-yield parameter sets, thus reliably precluding manipulation, for example resulting from changeovers being delayed across-the-board. In this case, the sequence of the parameter sets is changed from one cycle to the next.

Although the manipulation security is high when the entire control module is arranged with the expert, this increases the risk of incorrect operation of the wind energy installation, for example as a result of the lack of data transmission. For safe operation of the wind energy installation, it is critical for the various parameters in the parameter set to be specifically related to one another. If individual parameters are changed without taking account of the effects on other parameters, the wind energy installation can get out of control. The risk of incorrect operation can be reduced by splitting the control module into two separate units, specifically a control unit and a command transmitter. The control unit can be arranged together with the parameter memory in the wind energy installation. Restricting the control unit to the parameter sets stored in the parameter memory prevents the wind energy installation from accidentally being operated with incorrect parameter sets. In contrast, the command transmitter and the data memory can be arranged with the expert. The control unit receives commands from the command transmitter determining which of the parameter sets it should select from the parameter memory. Separating the control unit and the parameter memory results in a good compromise between operational reliability and manipulation security.

The invention will be described in the following text with reference, by way of example, to the attached drawing, in which:

Figure 1 shows a schematic illustration of the arrangement according to the invention;

Figure 2 shows a flowchart of the method according to the invention;

Figure 3 shows a schematic illustration of an arrangement according to the invention which is suitable for expert measurements; and

Figure 4 shows a flowchart of the arrangement shown in Figure 3.

5 A wind energy installation 1 to be measured is connected to a measurement device 2. The wind energy installation 1 comprises detectors, which are not illustrated, for various variables to be measured. The detectors are controlled by the measurement device 2, and measured values recorded by the detectors are  
10 passed to the measurement device 2.

The measurement device 2 is also connected to a microphone 3, which is used as a detector for the noise emission of the wind energy installation 1. There is a further connection between  
15 the measurement device 2 and an adjacent wind energy installation 4. Data relating to the wind conditions is transmitted from the adjacent wind energy installation 4 to the measurement device 2.

20 The measurement device 2 is connected not only to the adjacent wind energy installation 4 but to further adjacent wind energy installations. The measurement device 2 contains a selection unit which selects from the adjacent wind energy installations that arranged adjacent to the side of the wind energy  
25 installation 1, in the wind direction.

The interaction of the entire arrangement is coordinated by a control module 5. The control module 5 is connected to the wind energy installation 1 and to the measurement device 2.  
30 There are also connections to a parameter memory 6 and a data memory 7.

In the simple illustrated exemplary embodiment, three parameter sets P1, P2, P3 are stored in the parameter memory  
35 6. The data memory 7 contains measurement sets M1, M2, M3 associated with the parameter sets P1, P2, P3. Each of the measurement sets M1, M2, M3 comprises a plurality of measurement vectors V1, V2 ... Vn.

As shown in Figure 2, the measurement method starts at an undefined starting time 100. In step 110, the serial number of the measurement run  $i$  is set to the value 1. The actual measurement method starts at 120, by the control module 5 selecting a parameter set  $Pm_1$  from the parameter sets  $P1$ ,  $P2$ ,  $P3$  in the parameter memory 6. In step 130, the control module 5 transmits the selected parameter set  $Pm_1$  to the wind energy installation 1, and sets the wind energy installation 1 to an operating state which corresponds to the parameter set  $Pm_1$ . Once the non-stationary transient effects of the wind energy installation 1 have decayed, the measurement device 2 starts a measurement interval in step 140, in which measurement interval measurement data  $D$  is recorded by the detectors.

In step 150, the control module 5 then activates the memory set  $Mm_1$  associated with the parameter set  $Pm_1$  in the data memory 7. The measurement set  $Mm_1$  is therefore selected from the measurement sets  $M1$ ,  $M2$ ,  $M3$  as the memory location for the next data items to be stored. In step 160, the control module 5 retrieves the measurement data  $D$  from the measurement device 2 and passes it to the data memory 7. The data is stored in the data memory 7 in a measurement vector  $Vx$ , which is contained in the activated measurement set  $Mm_1$ , where  $x$  may assume one of the values 1 to  $n$ . Depending on the nature and the scope of the recorded measurement data  $D$ , the measurement data may also be stored in measurement matrices  $V1$ ,  $V2$  ...  $Vn$ , instead of in measurement vectors.

In the decision block 170, the control module determines that measurement data  $D$  has not yet been recorded for all the measurement vectors  $V1$  ...  $Vn$  of all the measurement sets  $M1$ ,  $M2$ ,  $M3$ . Once the serial number of the measurement run has been set to  $i = 2$  in 180, the second measurement run starts in step 120, with selection of a parameter set  $Pn_2$ .

The method ends in 190, when measurement data  $D$  has been recorded in  $i = 3*n$  measurement runs for all measurement

vectors  $V_1 \dots V_n$  of all measurement sets  $M_1, M_2, M_3$ . During the  $i = 3 \cdot n$  measurement runs, all the parameter sets  $P_{m_i}$  are selected from  $P_1, P_2, P_3$ , and therefore all the measurement sets  $M_{m_i}$  are selected from  $M_1, M_2, M_3$ , repeatedly, in a series of cycles.

The measurement of the various parameter sets and measurement sets effectively in parallel saves a considerable amount of time in comparison to sequential measurement. Since a plurality of different parameter sets are measured successively in a short sequence, this results in better comparability of the measurement, because the wind conditions remain substantially constant in the short time interval.

For expert measurements as shown in Figure 3, only one control unit 8 and the parameter memory 6 are components of the wind energy installation 1. A command transmitter 10 and the data memory 7 are arranged separately from the wind energy installation, with the expert. The command transmitter 10 is connected to the measurement device 2, to the control unit 8 and to the data memory 7.

Since the data relating to the wind conditions must likewise be recorded in an undisturbed flow and with manipulation security, it is not permissible in the case of expert measurements for the wind measurements to be carried out on an adjacent wind energy installation. In fact, a measurement mast 9 is installed in front of the wind energy installation in the prevailing wind direction, and wind sensors 11 are arranged at the tip of the measurement mast 9. The measurement mast 9 is connected for data transmission purposes via a line to the measurement device 2.

The measurement procedure shown in Figure 4 differs slightly from the method illustrated in Figure 2. In step 120, the control unit 8 selects the parameter set  $P_{m_i}$  in accordance with the demand from the command transmitter 10. Since there is no individual control module in which all the information is

joined together, the measurement device 2 requires a status message, in step 135, that the wind energy installation has been set in accordance with the parameter set  $Pm_i$ , before the measurement is started in step 140. The recording of the  
5 measured values in step 140, the selection of the measurement set  $Mm_i$  in step 150, and the storage of the data in the measurement vector  $Vx$  in step 160 are once again carried out under the control of the command transmitter 10.

## Patentkrav

1. Fremgangsmåde til udmåling af et vindkraftanlæg (1), ved hvilken tilordnede målesæt (M1, M2, M3) registreres for en  
5 flerhed af parametersæt (P1, P2, P3) i vindkraftanlægget (1), hvor målesættene (M1, M2, M3) omfatter målevektorer (V1...Vn), der følger tidsmæssigt efter hinanden, kendetegnet ved, at der skiftes mellem parametersættene (P1, P2, P3) i cyklusser, og at der for hvert parametersæt (P1, P2, P3) i mere end én  
10 cyklus registreres målevektorer (V1...Vn), hvor målevektorerne indeholder data, der er registreret inden for et måleinterval, og hvor parametersættet (P1, P2, P3) forbliver konstant, mens dataene for en målevektor (V1...Vn) registreres.
- 15 2. Fremgangsmåde ifølge krav 1, kendetegnet ved, at der udmåles mere end to parametersæt (P1, P2, P3).
3. Fremgangsmåde ifølge krav 1 eller 2, kendetegnet ved, at der for hver målevektor (V1...Vn) registreres data i mellem 1  
20 minut og 15 minutter, fortrinsvis i mellem 8 minutter og 12 minutter.
4. Fremgangsmåde ifølge et af kravene 1 til 3, kendetegnet ved, at der efter et skift af parametersættet (P1, P2, P3),  
25 inden den næste målevektor (V1...Vn) registreres, i en overgangsfase ventes på, at instationære overgangseffekter aftager.
5. Fremgangsmåde ifølge krav 4, kendetegnet ved, at  
30 overgangsfasen har en på forhånd fastlagt længde.
6. Fremgangsmåde ifølge krav 5, kendetegnet ved, at længden af overgangsfasen er afhængig af størrelsen, der skal måles.
- 35 7. Fremgangsmåde ifølge krav 4 kendetegnet ved, at længden af overgangsfasen bestemmes dynamisk.
8. Fremgangsmåde ifølge et af kravene 1 til 7, kendetegnet

ved, at parametersættet (P1, P2, P3) skiftes efter registreringen af hver enkelt målevektor (V1...Vn).

9. Fremgangsmåde ifølge et af kravene 1 til 7, kendetegnet ved, at parametersættet (P1, P2, P3) skiftes efter registreringen af en flerhed af målevektorer (V1...Vn).

10. Fremgangsmåde ifølge et af kravene 1 til 9, kendetegnet ved, at der for målevektorerne (V1...Vn) registreres data om udgangseffekt, netkompatibilitet, støjafgivelse og/eller svingningsforhold i vindkraftanlægget (1).

11. Fremgangsmåde ifølge et af kravene 1 til 10, kendetegnet ved, at der for målevektorerne (V1...Vn) registreres data om vindforholdene.

12. Fremgangsmåde ifølge krav 11, kendetegnet ved, at dataene om vindforholdene registreres på et tilstødende vindkraftanlæg (4).

13. Fremgangsmåde ifølge et af kravene 1 til 12, kendetegnet ved, at målesættene (M1, M2, M3) omfatter målematricer (V1...Vn), der er dannet af en flerhed af målevektorer.

14. Fremgangsmåde ifølge et af kravene 1 til 13, kendetegnet ved, at målevektorerne (V1...Vn) registreres i en rækkefølge af en forinden defineret prioritet.

15. Fremgangsmåde ifølge et af kravene 1 til 14, kendetegnet ved, at skiftet mellem parametersættene (P1, P2, P3) reguleres ved hjælp af en kommandoenhed (10), der er adskilt fra vindkraftanlægget (1).

16. Fremgangsmåde ifølge et af kravene 1 til 15, kendetegnet ved, at rækkefølgen af parametersæt (P1, P2, P3) ændrer sig fra cyklus til cyklus.

17. Anordning til udmåling af et vindkraftanlæg (1) med en

måleanordning (2) til registrering af målevektorer ( $V_1...V_n$ ), der følger tidsmæssigt efter hinanden, med et parameterlager (6) til lagring af parametersæt ( $P_1, P_2, P_3$ ), i det mindste et styremodul (5) til indstilling af vindkraftanlægget i henhold til parametersættene ( $P_1, P_2, P_3$ ) såvel som et datalager (7), der er dimensioneret til at lagre målevektorerne ( $V_1...V_n$ ) i målesæt ( $M_1, M_2, M_3$ ), der er tilordnet parametersættene ( $P_1, P_2, P_3$ ), kendetegnet ved, at styremodulet (5) desuden er dimensioneret til inden for cyklusser at vælge et parametersæt ( $P_{mi}$ ) ud fra parametersættene ( $P_1, P_2, P_3$ ) og efter hver enkelt valgt at aktivere målesættet ( $M_{mi}$ ), der er tilordnet det valgte parametersæt ( $P_{mi}$ ), i datalageret (7), hvor målevektorerne indeholder data, der er registreret inden for et måleinterval, og hvor parametersættet ( $P_1, P_2, P_3$ ) forbliver konstant, mens dataene til en målevektor ( $V_1...V_n$ ) registreres.

18. Anordning ifølge krav 17, kendetegnet ved, at parameterlageret (6) og datalageret (7) er placeret i et lagermodul (6,7).

19. Anordning ifølge krav 17 eller 18, kendetegnet ved, at styremodulet (5) er integreret i vindkraftanlægget (1).

20. Anordning ifølge krav 17, kendetegnet ved, at styremodulet omfatter en styreenhed (8) og en kommandoenhed (10), og at styreenheden (8) udvælger parametersættene ( $P_{mi}$ ) i henhold til kommandoer, der er modtaget fra kommandoenheden (10).

21. Anordning ifølge krav 20, kendetegnet ved, at kommandoenheden (10) og datalageret (7) er placeret adskilt fra vindkraftanlægget (1).

22. Anordning ifølge et af kravene 17 til 21, kendetegnet ved, at en vindmåler fra et tilstødende vindkraftanlæg (4) er tilordnet den

23. Anordning ifølge krav 22, kendetegnet ved, at der er tilvejebragt en udvalgsenhed (2), der er udformet til at tilordne et i vindretningen lateralt tilstødende vindkraftanlæg (4).

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24. Anordning ifølge et af kravene 17 til 23, kendetegnet ved, at den omfatter en detektor for svingningsforholdet og/eller en detektor (3) for støjafgivelsen i vindkraftanlægget (1).

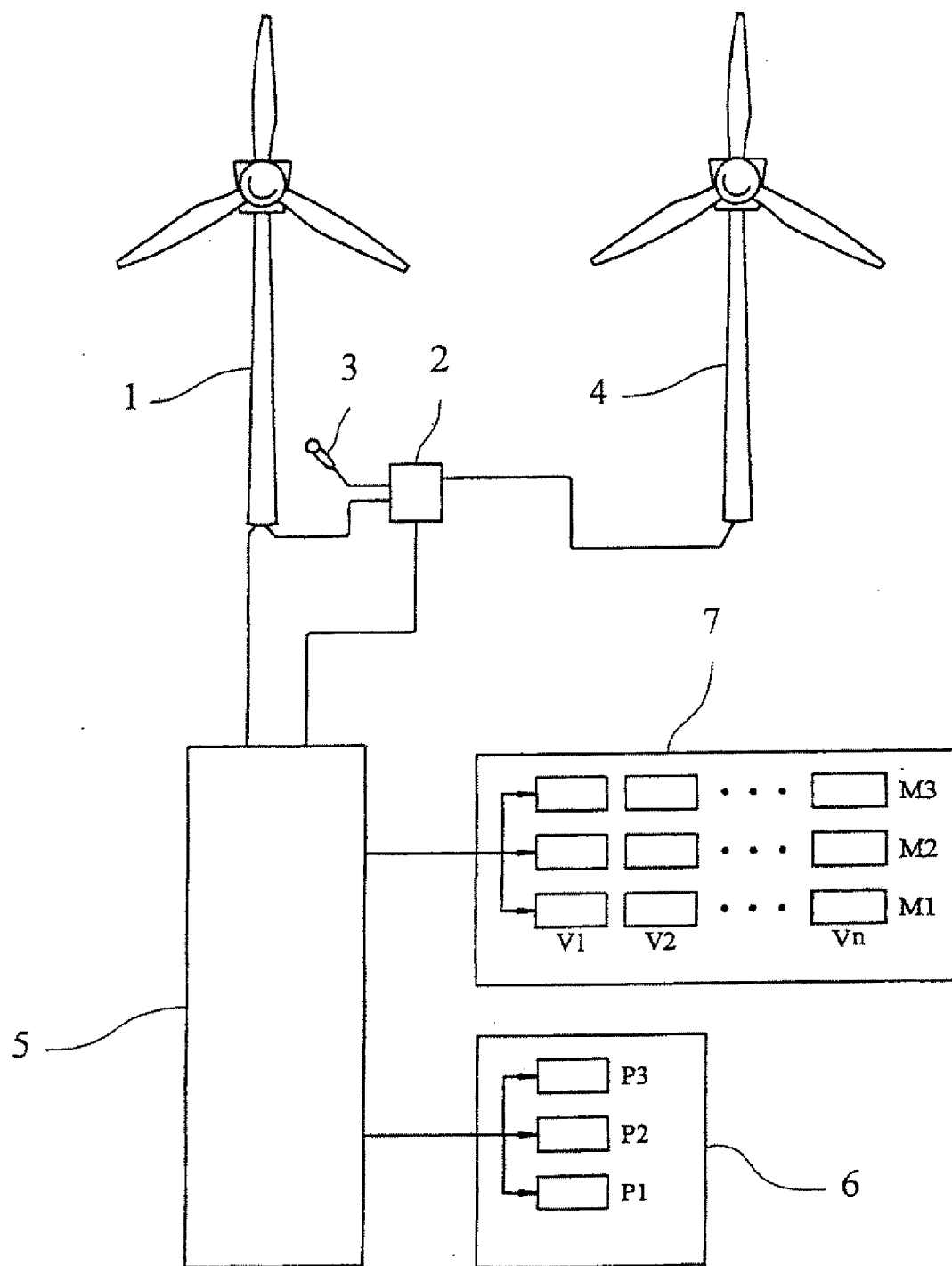


Fig. 1

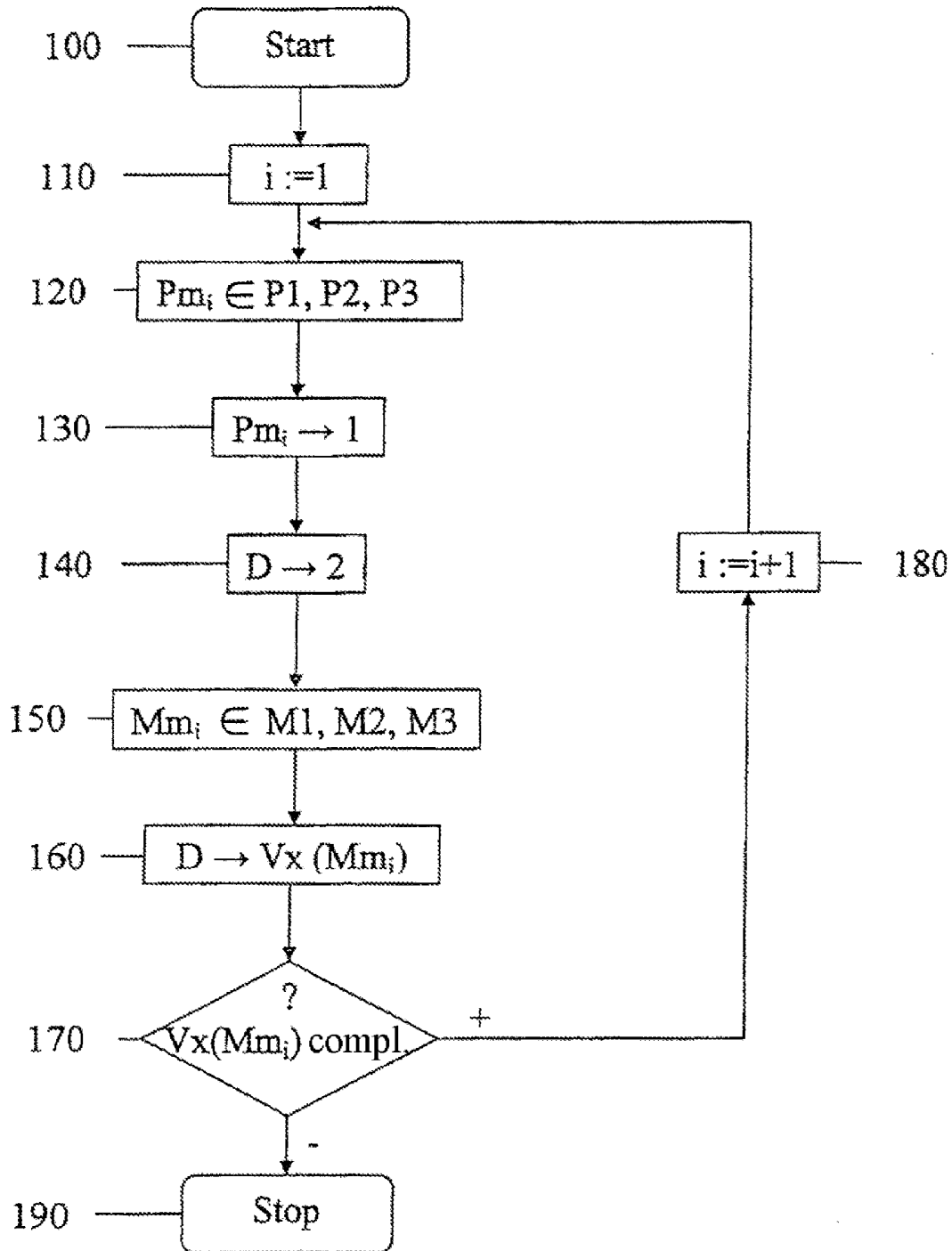


Fig. 2

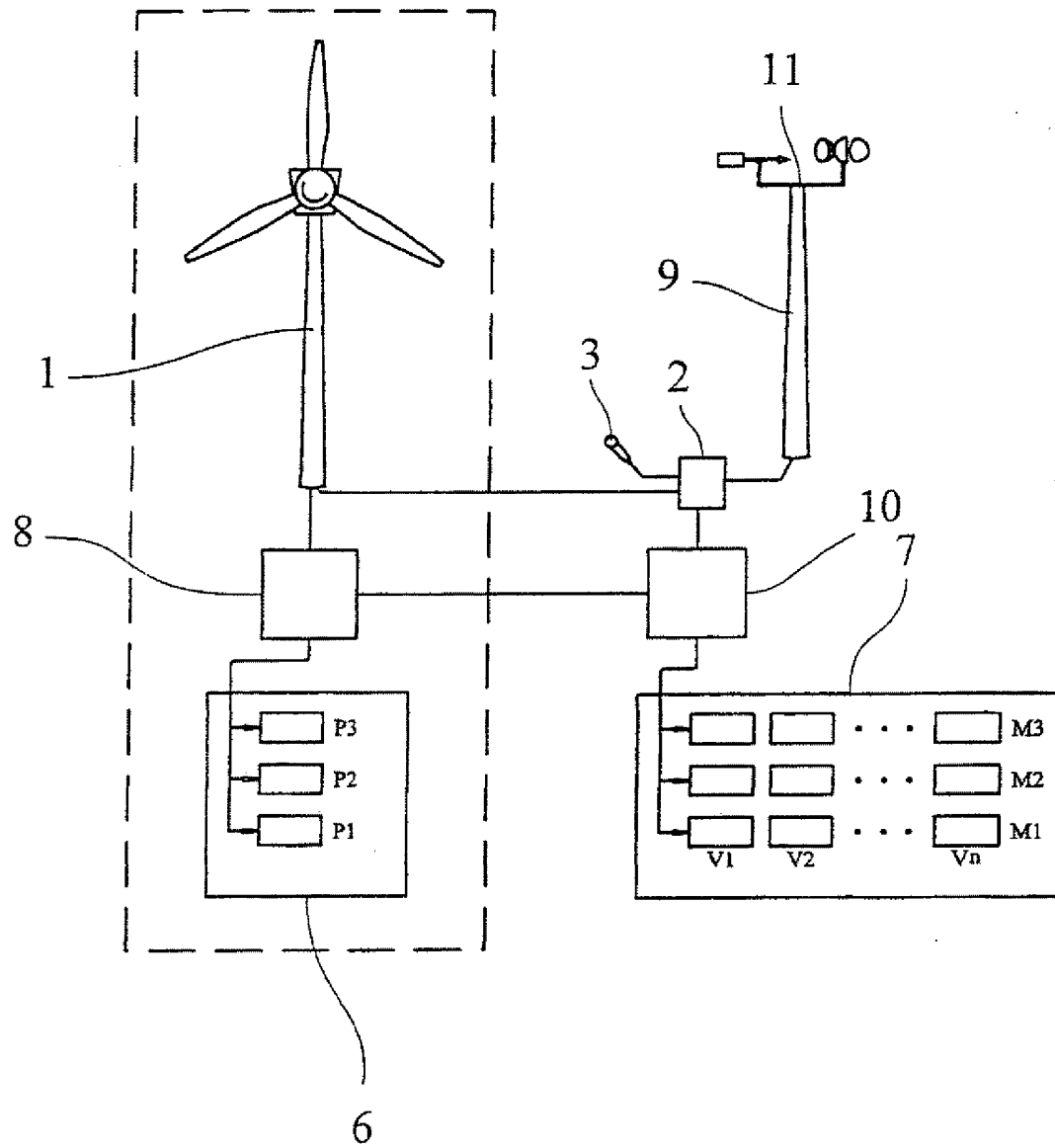


Fig. 3

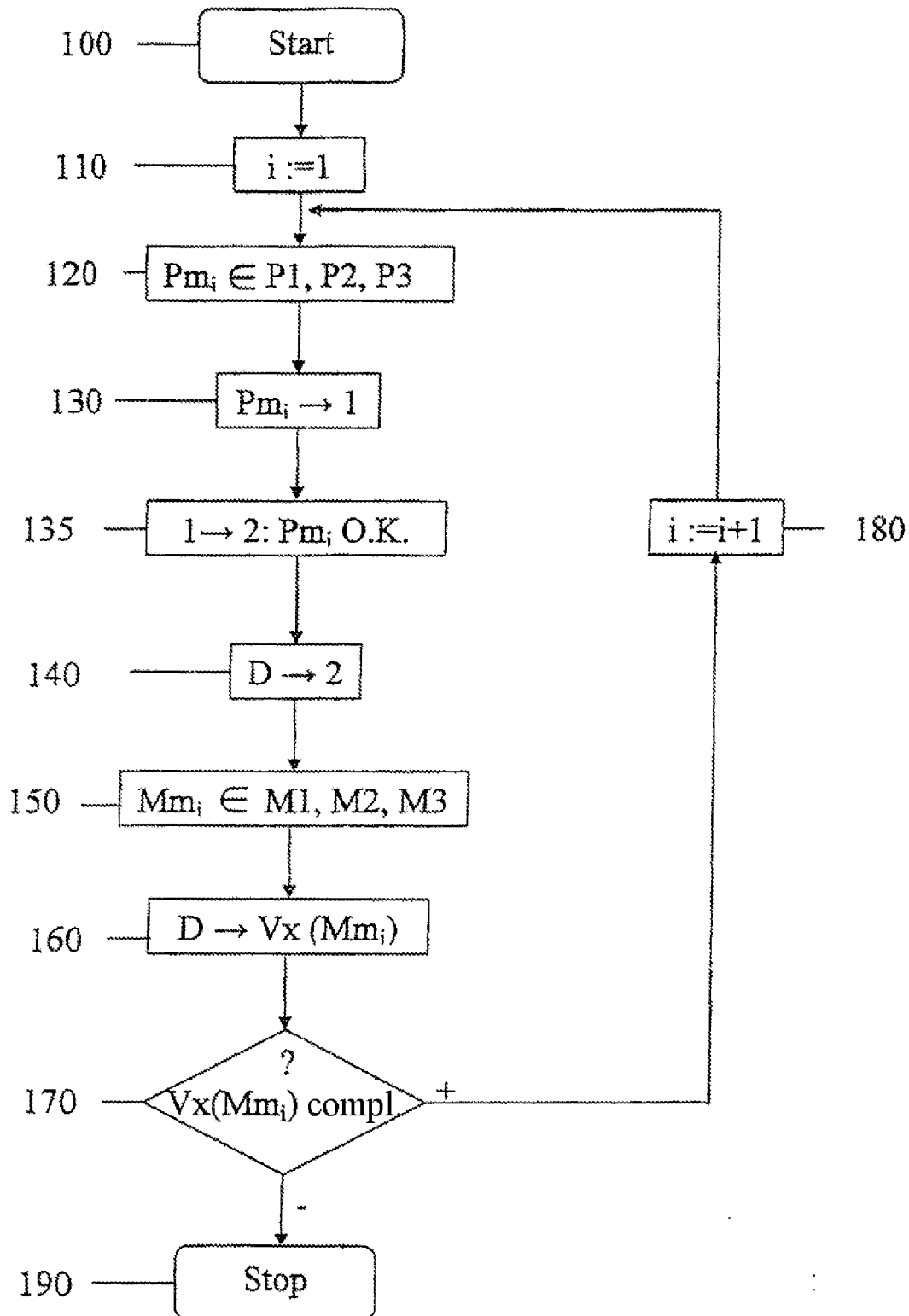


Fig. 4