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Datasheet for the decision of 20 January 2016

Case Number: T 0514/12 - 3.5.03

Application Number: 07020028.2

Publication Number: 2048562

IPC: G05B23/02, G05B13/04

Language of the proceedings: EN

Title of invention:
Method and device for providing at least one input sensor signal for a control and/or monitoring application and control device

Patent Proprietor:
Siemens Aktiengesellschaft

Opponent:
Vestas Wind Systems A/S

Headword:
Virtual sensor signal/SIEMENS

Relevant legal provisions:
EPC Art. 56
RPBA Art. 13(1)

Keyword:
Inventive step - main request (no)
Admissibility of late-filed auxiliary requests 1 and 2 (no)

Decisions cited:

Catchword:

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Case Number: T 0514/12 - 3.5.03

D E C I S I O N
of Technical Board of Appeal 3.5.03
of 20 January 2016

Appellant: (Patent Proprietor)	Siemens Aktiengesellschaft Wittelsbacherplatz 2 80333 München (DE)
Representative:	Siemens AG Postfach 22 16 34 80506 München (DE)
Respondent: (Opponent)	Vestas Wind Systems A/S Alsvej 21 8940 Randers (DK)
Representative:	Lloyd, Patrick Alexander Desmond Reddie & Grose LLP 16 Theobalds Road London WC1X 8PL (GB)
Decision under appeal:	**Decision of the Opposition Division of the European Patent Office posted on 27 December 2011 revoking European patent No. 2048562 pursuant to Article 101(3)(b) EPC.**

Composition of the Board:

Chairman	F. van der Voort
Members:	T. Snell
	P. Guntz

Summary of Facts and Submissions

I. This appeal was lodged by the proprietor against the decision of the opposition division revoking European patent No. EP 2048562 on the grounds, inter alia, that the subject-matter of claim 1 of a main request and a first auxiliary request respectively was not new with respect to the disclosure of A2 (see below), and that the subject-matter of claim 1 of second and third auxiliary requests respectively did not involve an inventive step.

II. The following documents are mentioned in the reasons for the board's decision:

A1: E.A. Bossanyi, "Adaptive pitch control for a 250 kW wind turbine", Proceedings of the 9th BWEA conference 1987, pages 85-92;
A2: E.A. Bossanyi, "The Design of Closed Loop Controllers for Wind Turbines", Wind Energy 2000, No. 3, pages 149-163;
A3: E.A. Bossanyi, "Individual Blade Pitch Control for Load Reduction", Wind Energy, No. 6, 2003, pages 119-128; and
A10: US 2006/0033338 A1.

III. In the notice of appeal, the proprietor (henceforth, appellant) requested that the decision be set aside. In the subsequently filed statement of grounds of appeal, the appellant requested as a main request that the patent be maintained as granted, i.e., implicitly, that the opposition be rejected. Alternatively, the appellant requested that the patent be maintained in amended form on the basis of one of first to fourth auxiliary requests, all filed together with the statement of grounds of appeal.

IV. In a response to the appeal, the opponent (henceforth, respondent) requested that the decision be upheld, i.e., implicitly, that the appeal be dismissed. With respect to novelty and inventive step, the respondent referred, *inter alia*, to documents A1 to A5 (which are articles by the same author) and A10

V. Both parties conditionally requested oral proceedings.

VI. In a communication accompanying a summons to attend oral proceedings, the board gave a preliminary opinion that the subject-matter of claim 1 of the main request either was not new or at least did not involve an inventive step with respect to A2. The board also raised matters concerned with Articles 84 and 123(2) EPC with respect to claim 1 of the auxiliary requests, and gave its preliminary opinion that the subject-matter of claim 1 respectively of the first and second auxiliary requests was either not new, or at least did not involve an inventive step, and the subject-matter of claim 1 respectively of the third and fourth auxiliary requests did not involve an inventive step (Articles 52(1) and 56 EPC), principally in the light of the disclosure of A2, but corroborated by the disclosures of other documents, *inter alia* A1 and A3.

The board also stated that document A10 appeared to be highly relevant. This document had been mentioned by the respondent in the reply to the statement of grounds of appeal, in combination with A2.

VII. In a response to the board's communication, the appellant submitted claims of first to fourth auxiliary requests to replace the auxiliary requests on file.

VIII. The respondent submitted detailed comments with respect to novelty and inventive step starting out from document A10.

IX. Oral proceedings took place on 20 January 2016.

During the oral proceedings, the appellant filed new first and second auxiliary requests to replace all auxiliary requests on file.

The appellant requested that the decision under appeal be set aside and that the opposition be rejected (main request) or, in the alternative, that the patent be maintained in amended form on the basis of either auxiliary request 1 or auxiliary request 2, both as filed at the oral proceedings.

The respondent requested that the appeal be dismissed.

At the conclusion of the oral proceedings, after due deliberation, the chairman announced the board's decision.

X. Claim 1 of the **main request**, i.e. claim 1 as granted, reads as follows:

"A method of providing at least one input sensor signal for a control and/or monitoring application (13) regarding an installation (1), comprising the steps of:
- providing at least one real sensor signal based on at least one quantity measured at the installation (1);
- providing at least one dynamical model of the installation;
- estimating states on at least the basis of the at least one sensor signal using the dynamical model;

- generating at least one virtual sensor signal from the estimated states by calculating at least one local condition at the installation from the estimated states and establishing the at least one virtual sensor signal from the at least one local condition;
- providing the at least one virtual sensor signal as the at least one input sensor signal for the control and/or monitoring application (13),
characterised in that
- the installation is a wind turbine (1),
- the dynamic model comprises a representation of structural dynamics of the wind turbine (1) and their interaction with wind shears and/or the wake of the wind turbine,
- the estimated states are wind shears and/or wake states and/or estimated structural states of the wind turbine(1); and
- the control and/or monitoring application is one of the following:
(a) a blade aerodynamic control (13) based on an aerodynamic input based on local flow conditions where the at least one virtual sensor signal represents a local wind flow condition;
(b) a pitch servo control based on bearing forces and/or bearing moments where the at least one virtual sensor signal represents a bearing force and/or a bearing moment;
(c) a fatigue damage estimator based on long-term loads where the at least one virtual sensor signal represents a load within the wind turbine (1)."

XI. Claim 1 of auxiliary request 1 reads as follows:

"A method of providing at least one input sensor signal for a control and/or monitoring application (13) regarding an installation (1), comprising the steps of:

- providing at least one real sensor signal based on at least one quantity measured at the installation (1);
- providing at least one dynamical model of the installation;
- estimating states on at least the basis of the at least one sensor signal using the dynamical model;
- generating at least one virtual sensor signal from the estimated states by calculating at least one local condition at the installation from the estimated states and establishing the at least one virtual sensor signal from the at least one local condition;
- providing the at least one virtual sensor signal as the at least one input sensor signal for the control and/or monitoring application (13),

wherein

- the installation is a wind turbine (1),
- the dynamic model comprises a representation of structural dynamics of the wind turbine (1) and their interaction with wind shears and/or the wake of the wind turbine,
- the estimated states are wind shears and/or wake states and/or estimated structural states of the wind turbine (1); and
- the control and/or monitoring application is a blade aerodynamic control (13) based on an aerodynamic input based on local flow conditions where the at least one virtual sensor signal represents a local wind flow condition, the local flow is calculated from vector relations between estimated wind speed components and estimated structural states, and the virtual sensor signal represents an estimated wind speed and/or the wind's angle of attack."

XII. Claim 1 of **auxiliary request 2** reads as follows:

"A device (10) for providing at least one input sensor signal for a control and/or monitoring device regarding an installation (1), comprising:

- at least one model unit (7) containing a dynamical model of the installation (1) which is designed to output a model representation of the installation (1);
- at least one state estimator (5) which contains a sensor signal input connectable to an output of a sensor (3) of the installation (1) for receiving a real sensor signal provided by said sensor (3), the at least one state estimator (5) being connected to the at least one model unit (7) for receiving a model representation of the installation (1) and being designed to estimate states on at least the basis of the at least one real sensor signal and the model representation of the installation (1) and to output said estimated states; and
- at least one signal generator (9) which is connected to the state estimator (5) for receiving estimated states, the signal generator being designed to generate at least one virtual sensor signal from the estimated states and comprising an output connectable to a control and/or monitoring device (13) for outputting said at least one virtual sensor signal,

wherein

- the installation is a wind turbine (1),
- the dynamic model comprises a representation of structural dynamics of the wind turbine (1) and their interaction with wind shears and/or the wake of the wind turbine,
- the estimated states are wind shears and/or wake states and/or estimated structural states of the wind turbine(1); and
- the control and/or monitoring application is a blade aerodynamic control (13) based on an aerodynamic input based on local flow conditions where the at least one

virtual sensor signal represents a local wind flow condition, the local flow is calculated from vector relations between estimated wind speed components and estimated structural states, and the virtual sensor signal represents an estimated wind speed and/or the wind's angle of attack."

Reasons for the Decision

1. Introduction

The present patent relates to the control of wind turbines, e.g. the control of the pitch angle of each blade. In essence, it is concerned with generating a "virtual sensor signal", which represents a parameter of the wind turbine system which is either difficult to measure by a real sensor, or is not measurable at all (cf. paragraph [0013] of the description). This virtual sensor signal is then used in a control and/or monitoring application, in particular blade aerodynamic control, pitch servo control, or fatigue damage estimation (cf. claim 1 of the patent).

2. Main request - claim 1 - novelty and inventive step

2.1 The closest prior art was held by the opposition division to be A2. This has not been disputed. A2 is a document giving an overview of different methods of controlling wind turbines. The most relevant part of A2 is the section beginning on page 159 entitled "Advanced Controllers". This section mentions *inter alia* "self-tuning controllers" and "LQG/optimal feedback [controllers]". In relation to "self-tuning controllers" it is stated that "If the system dynamics are known .... a linearized physical model is used to predict sensor outputs, and the prediction errors are used to update estimates of the system state variables. These variables may include rotational speeds, torques, deflections, etc. as well as the actual wind speed, so their values can be used to calculate appropriate control actions even though those particular variables are not actually measured". In the board's view, estimates of the system state variables referred to here are "virtual sensor signals" within the meaning of the patent in suit, since they represent physical parameters which in theory could be measured by a sensor.

2.2 In the section entitled "State Estimators", it is then stated that "Alternatively, using a full model of the dynamics, a Kalman filter can be used to estimate all the system states from the prediction errors". It would be obvious to the skilled person that the "system states" referred to here may include at least some of those system state variables listed in connection with self-tuning controllers.

2.3 The "Kalman filter" embodiment is described in more detail in the next section entitled "Optimal Feedback", which describes an LQG ("linear-quadratic-gaussian") controller, depicted in Figure 4 on page 160. In essence, a Kalman filter block is shown in which, based on the dynamic model, signals representing predicted states x'(k) and predicted measurements y'(k) are generated. The predicted measurements are then compared with the real measurements y(k), and the output of the comparison used to correct the predicted states x'(k) to form output signals x(k) which represent the estimated states. At least some of these estimated states x(k), insofar as they concern theoretically measurable quantities, are considered to be virtual sensor signals within the meaning of the present patent.

2.4 As a preliminary remark, the board notes that the opposition division held that the subject-matter of claim 1 was not new with respect to A2 (which is also the position of the respondent). However, since their analysis relies on passages of A2 taken from different sections of the document which are not explicitly described in combination, the board finds that novelty is not the issue here, only inventive step.

2.5 Using the language of claim 1, document A2 (cf. in particular Figure 4) discloses a method of providing at least one input sensor signal ("x(k)") for a control and/or monitoring application regarding an installation, comprising the steps of:
- providing at least one real sensor signal ("y(k)") based on at least one quantity measured at the installation;
- providing at least one dynamical model of the installation ("Turbine dynamics");
- estimating states ("x(k)") on at least the basis of the at least one [real] sensor signal ("y(k)") using the dynamical model;
- generating at least one virtual sensor signal ("x(k)");
- providing the at least one virtual sensor signal as the at least one input sensor signal for the control and/or monitoring application (see point 2.6 below),
wherein
- the installation is a wind turbine,
- the dynamic model comprises a representation of structural dynamics of the wind turbine and their interaction with wind shears and/or the wake of the wind turbine (the appellant did not contest that this

was at least implicit in A2, cf. page 162, the section entitled "Simulation Methods"),
- the estimated states ("x(k)") are wind shears and/or wake states and/or estimated structural states of the wind turbine (cf. page 159, the section entitled "Advanced Controllers", last paragraph, "rotational speeds, torques, deflections etc. as well as the actual wind speed"; cf. also point 2.10.1 below).

2.6 The appellant argued that the values x(k) in Figure 4 are not input to a control application, but are merely fed back into the Kalman filter to improve the calculation of the estimated states. The board does not accept this argument, since the whole purpose of the controller is to generate signals for controlling the wind turbine, e.g. blade pitch control, and it is explicitly stated that the values of system state variables, i.e. some of the virtual sensor signals x(k), "can be used to calculate appropriate control actions even though those particular variables are not actually measured" (cf. page 159, "Advanced Controllers", last sentence). Also the values x(k) are used to generate control signals u(k) by means of a linear cost function (cf. page 159, section entitled "Optimal Feedback", lines 1-7). These control outputs may include pitch demand and torque demand output signals (cf. page 160, lines 5-7).

2.7 The subject-matter of claim 1 differs from the method disclosed in D2 using the LQG controller shown in Figure 4 in that, according to claim 1:

(i) the virtual sensor signal is generated from the estimated states by calculating at least one local condition at the installation from the estimated states and establishing the at least one virtual sensor signal from the at least one local condition; and

(ii) the virtual sensor signal is provided as input sensor signal for one of the following three application (cf. features (a), (b) and (c) of claim 1):

(a) a blade aerodynamic control based on an aerodynamic input based on local flow conditions where the at least one virtual sensor signal represents a local wind flow condition;
(b) a pitch servo control based on bearing forces and/or bearing moments where the at least one virtual sensor signal represents a bearing force and/or a bearing moment; and
(c) a fatigue damage estimator based on long-term loads where the at least one virtual sensor signal represents a load within the wind turbine.

2.8 The board firstly notes that the term "local" does not meaningfully limit claim 1. Any system parameter is local at least in the sense of being local to the wind turbine in question. The appellant drew a distinction between "global" and "local" conditions. The board however does not see any clear distinction. In any case, conditions at a specified location, e.g. rotational velocity, can be representative of a global condition, e.g. where all parts of the system rotate at the same speed. It follows that a global condition can also reflect a local condition at a specific location.

2.9 Re (i):

2.9.1 The appellant argued that this feature requires two steps: firstly the system states are estimated, and secondly a "local condition" is calculated from which the virtual sensor signal is established. Further, the appellant argued that the virtual sensor signal was a physical parameter entirely different to the estimated states from which it was calculated, and not merely a corrected version of these estimated states.

2.9.2 It was apparently conceded by the appellant that the virtual sensor signal and the local condition could effectively be the same signal, which interpretation is in conformity with the description, cf. e.g. paragraph [0047] of the patent, lines 1-3.

2.9.3 For the sake of argument, the appellant's interpretation of claim 1 that the "virtual sensor signal" is a different parameter from the state estimates from which it is calculated is adopted. However, even in this case, feature (i) does not contribute to inventive step. The LQG controller of A2, Figure 4, operates on the basis of having a complete model of the dynamics of the system and produces an output vector x(k) containing estimates of <u>all</u> system states. The virtual sensor signals of the present invention, which represent unmeasured parameters, are also states of the system and thus would be included in a vector of all states. In the board's view, it is obvious, if not implicit, that certain unmeasured states in the vector x(k) may be calculated from other states in the vector x(k), based on the dynamic relationships defined in the dynamic model. This is exemplified in more detail by document A1 (by the same author), which gives an example of a state-space model based on the Kalman filter approach (i.e. an analogous approach to that used in A2, Figure 4) in which the vector x contains the state variables of blade pitch, shaft speed, wind speed and generator torque (cf. A1, page 87, right-hand col., lines 21-22). Rotor torque, which is the controlled variable, is calculated from the first three state variables (cf. A1, page 87, right-hand col., lines 29-31). Therefore, using the terminology of claim 1, blade pitch, shaft speed and wind speed can be considered "estimated states", and rotor torque would be the "local condition"/"virtual sensor signal" (note that rotor torque need not be measurable, cf. A1, section 3.4). A2 also gives examples of dynamic relationships between state variables: wind shear and upflow may be correlated with wind direction (cf. page 158, lines 12-13), blade root loads can be derived from accelerometers (cf. page 158, last paragraph), and wind speed seen by the rotor can be estimated from the measured power and/or rotational speed and the pitch angle (cf. page 159, the section entitled "Observers"). Therefore, the board concludes that calculating a local condition/virtual sensor signal from estimated states does not contribute to inventive step.

2.10 Re (ii):

2.10.1 Re (a): It is disclosed in A2 that the "actual wind speed" may be an estimated system variable which is not actually measured, i.e. a virtual sensor signal (cf. page 159, "Advanced Controllers", last paragraph and "Observers"). Actual wind speed is a "local flow condition". It is also disclosed in A2 that blade pitch control ("pitch demand", cf. page 160, line 7) may be an output signal. Although the mentioning of actual wind speed is not explicitly disclosed in connection with aerodynamic blade control in the section describing the embodiment of Figure 4, the board notes that in the section on page 159 entitled "Observers", it is stated that "The estimated wind speed can then be used to define the appropriate desired pitch angle".

Therefore, in the context of Figure 4, feature (a) is obvious.

2.10.2 Re (b): In A2, torque is mentioned as a candidate variable which is not actually measured, i.e. a virtual sensor signal. Since torque is obviously related to a bearing moment, and since pitch control is obviously affected by torque, alternative (b) is also obvious. Furthermore, document A3 (also by the same author) describes a further example of a wind turbine blade pitch controller based on an LQG controller having the same basic structure as Figure 4 of A2 (cf. A3, page 122, Figure 1). Clearly, A2 and A3 are closely related documents, which was not apparently disputed by the appellant. In the example of an LQG controller in A3, blade root load sensors are used as inputs (cf. page 126, lines 8-9), and yaw bearing moments are produced as outputs (cf. page 124, Figure 3). These latter are regarded as virtual sensor signals.

2.10.3 Re (c): Figure 5 of A3 shows "damage equivalent loads" as a histogram, *inter alia* for a differential LQG controller. Damage equivalent loads are a measure of equivalent fatigue damage. Certain of them are apparently based on virtual sensor signals representing long term loads, namely "Yaw bearing Mz", "Yaw bearing My" and "Shaft My".

2.10.4 Consequently, alternatives (a), (b) and (c) are either obvious having regard to A2 alone, or when seen in combination with A3 (noting of course that feature (ii) would not contribute to inventive step already if only one of these alternatives were held to be obvious).

2.11 The board concludes that the subject-matter of claim 1 of the main request does not involve an inventive step (Articles 52(1) and 56 EPC).

3. Auxiliary request 1 - admissibility

3.1 Claim 1 of auxiliary request 1 differs from claim 1 of the main request in that it is limited to option (a) of claim 1 of the main request, and in that the following wording is added to option (a):

"the local flow is calculated from vector relations between estimated wind speed components and estimated structural states, and the virtual sensor signal represents an estimated wind speed and/or the wind's angle of attack".

3.2 The request was filed during the oral proceedings, and thus its admitting is at the discretion of the board (Article 13(1) RPBA). The respondent requested that the request be not admitted, particularly in the light of Articles 12(1), (2) and (4) and 13(3) RPBA. The respondent stated that the request had been filed at very short notice and that time would be needed to study the request. Consequently, the request raised issues which could not be dealt with in the oral proceedings.

3.3 Before deciding on admissibility, the board allowed a discussion with respect to inventive step in order to assess whether there was a prospect of the new request overcoming the objections raised in connection with the main request.

3.4 The appellant essentially repeated the same argument made in connection with the main request that A2 gives no hint to the variables being used as input signals to a control application (cf. point 2.6 above).

3.5 The respondent pointed to several passages of A2 which referred to control actions, and also noted again the disclosure of an estimated wind speed being used as a control signal. The respondent also drew attention to document A10, which, prima facie, disclosed that the estimated wind speed was used in a control application. As regards the vector relations defined in claim 1, the respondent argued that this was no more than "basic maths".

3.6 As already discussed in connection with the main request, A2 already suggests that the estimated wind speed may be input to a control application. Therefore, the board agrees with the respondent that using an estimated wind speed as a virtual sensor signal for a control application does not contribute to inventive step. There is therefore no need to consider A10, even if the board agrees that it prima facie also discloses that estimated wind flow is used to control a wind turbine (cf. Fig. 2 and the abstract).

3.7 As to the requirement in claim 1 that the local [wind] flow is calculated from vector relations between estimated wind speed components and estimated structural states, the board notes that A2 already suggests that estimated wind speed can be calculated from structural states. Furthermore, calculations in a Kalman filter are apparently generally implemented based on vector relations. This is clear from A3, cf. page 122. Consequently, the board could see no prospect that this aspect could contribute to inventive step either, especially as the appellant had not himself presented any arguments to that effect.

3.8 Considering the state of the proceedings and the need for procedural economy, particularly with regard to the fact that the newly added features of claim 1 of auxiliary request 1 would prima facie not have overcome the objection of lack of inventive step, the board exercised its discretionary power under Article 13(1) RPBA by not admitting the request.

4. Auxiliary request 2 - admissibility

4.1 Claim 1 of auxiliary request 2 (which is the same as claim 14 of auxiliary request 1) is a device claim which comprises apparatus features largely corresponding to method claim 1 of auxiliary request 1. The appellant argued that claim 1 of auxiliary request 2 had additional structural limitations, e.g. a "signal generator (9) which is connected to the state estimator (5) for receiving estimated states" (cf. Fig. 1 of the patent).

4.2 The board however considers that the "apparatus" features of claim 1 of auxiliary request 2, particularly those forming part of the device 10 in Fig. 1, are more to be understood as being functional sub-blocks rather than as separate hardware items. Processing in such systems is in any case generally carried out by a program run on a processor. The board therefore attributes no particular significance to these additional "structural" limitations. The appellant also did not provide arguments as to why these structural limitations involved an inventive step.

4.3 Considering the state of the proceedings and the fact that the newly added features of claim 1 of auxiliary request 2 would prima facie not have overcome the objection of lack of inventive step, the board exercised its discretionary power under Article 13(1) RPBA by not admitting this request either.

5. *Conclusion*

As none of the appellant's requests are allowable, it follows that the appeal must be dismissed.

Order

For these reasons it is decided that:

The appeal is dismissed.

The Registrar: The Chairman:

D. Magliano F. van der Voort

Decision electronically authenticated