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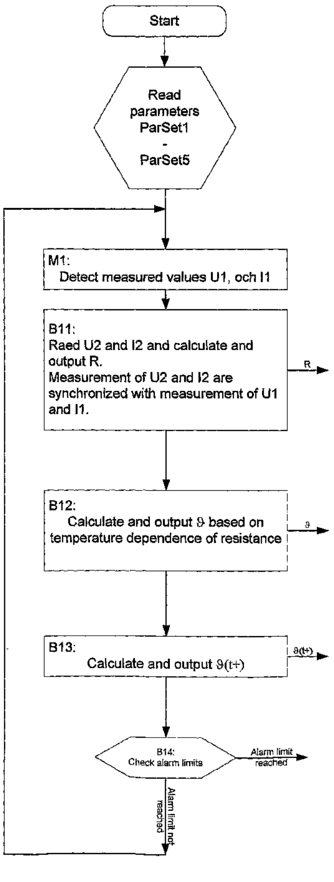
[Continued on next page]

(54) Title: A METHOD AND A DEVICE FOR DETERMINING THE LOAD STATE OF POWER SYSTEM COMPONENTS



(57) Abstract: The invention relates to a method for determining the load state in a power system component, such as a line, in an electric power system. The invention is achieved by: determining the reference temperature for the conductor material, determining current and voltage on the line, transferring these values to a calculating unit, calculating a value for the actual resistance of the line, based on current and voltage values, calculating the temperature, and hence the degree of load, of the line based on the above values. The invention also relates to a system and a computer program for carrying out the method.

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A method and a device for determining the load state of power system components

Technical field

The present invention relates to a method for determining the load state for the components of a power system in an electric power system, and a system for carrying out the method. The method and the system are especially related to the resistive temperature dependence of electric power system components.

The device comprises measurement and control equipment intended to be used in an electric power system.

Background of the invention and prior art

Electric power systems are planned and designed for normal as well as disturbed operation, and the dimensioning criteria laid down relating to system quantities and power transmissions are used for that purpose. The load state, expressed as temperature, through power, current, voltage, linear expansion or sagging, for components in various parts of the electric power system, is one such quantity. This load state, related to a limit or reference value, is a measure of the degree of utilization of the component and sometimes also a measure of the margin of stability of the system.

To achieve cost effectiveness, it becomes increasingly more important to utilize the different components of the power system up to their thermal limits, which in turn are dependent on factors such as material changes, line sag, or the risk of breakdown in insulating material. Since the operation of the power systems is limited by thermal transmission limits, it is also increasingly becoming a requirement from clients to enclose thermal overload protective devices in the electric power systems.

To be able to utilize the power system components in the proper way, some form of temperature estimation is thus required, which is currently performed by measurement or calculation. For power system components of a moderate extent, for example transformers, generators and shunt elements, temperature sensors may be mounted into the apparatus itself, which is a method that is not equally suited for elongated components, such as power cables and overhead transmission lines.

Especially for lines, but also for transformers, methods have been developed for determining the temperature in the various parts of the component, based on the second main theorem of the thermodynamics [Gabriel Benmoyal and co-authors, Western Protective Relay Conference, Spokane, 2003]. Unfortunately, these calculations contain many quantities that are associated with the heat dissipation and are difficult to determine, such as cooling by wind and precipitation, radiation from the sun, etc., and therefore have a clearly limited value for practical use since it is relatively simple to set up the equations and define the parameters and quantities included, but it is very difficult to determine the parameters that are characteristic of the power system component under consideration.

Another method is to utilize the variation with the temperature of the electric resistance in different materials, which is used in various types of temperature sensors for point-by-point or local temperature measurement.

Objects and most important characteristics of the invention

The object of the invention is to suggest a method and a system for determining the load state of power system components, based on an accurate determination of the conductor resistance of the component, preferably based on measured current and voltage, in order to determine, from the temperature dependence of the resistance, the conductor temperature for the conductor material of the component in question.

The above object and other objects are achieved according to the invention by a method according to claim 1, by a system according to claim 7, and by a computer program according to claim 13.

By basing the temperature measurement on an accurate resistance measurement, all uncertainties based on uncertain and variable data influencing the heat dissipation, such as meteorological data, are avoided.

For determining the thermal load state on a line, current and voltage are measured at both end points of the line, preferably synchronized measurement of the complex phase quantities but also the positive-sequence components may be measured, and the current contribution from the equivalent shunt elements, and any shunt elements connected to the line, are calculated. Thereafter, the resistance of the line is calculated, and with knowledge of the temperature dependence of the conductor material and the resistance of the conductor at a certain reference temperature, the conductor temperature may be determined.

Brief description of the accompanying drawings

The invention will be described in greater detail below with reference to the accompanying figures.

Figure 1 shows a line in an electric power system with circuit breakers at both ends, equivalent shunt branches and instrument transformers.

Figure 2 shows an embodiment of a calculating unit for determining the load state of a line.

Figure 3 shows an embodiment of the invention in a flow chart, based on the components in Figure 2.

Description of preferred embodiments of the invention

Figure 1 shows a line L1 in an electric power system with associated circuit breakers S1, S2 at both ends of the line, equivalent shunt branches Zs1, Zs2, instrument transformers E1a,b and E2a,b for measuring the currents I1, I2 as well as the voltages U1, U2. The measuring unit M1 is placed at the transmitter end of the line L1 and the measuring unti M2 at the receiver end of the line L1. The calculating unit B1 is connected to the transmitter end of the line L1 and includes the measuring unit M1. A communication C1 between the measuring units M1, M2 is achieved via, for example, an optical fibre or a microwave link. The synchronization of the measurements at both end points of the line may be made via GPS-controlled time synchronization C2.

Figure 2 shows an embodiment of the described calculating unit B1 that determines the load state of a line. Instrument transformers E3, E4 are arranged for measuring voltage and current, respectively, of the line L1 in question. The instrument transformers E3, E4 are connected to the measuring unit M1 and provide, together with the parameter set ParSet1, the measurement quantities U1 and I1, which together with the measurement quantities U2 and I2, from the remote end of the line, via the communication link C1, and the parameter set ParSet2, form the basis for calculating the resistance R of the line in the calculating element B11. In the calculating element B12, the temperature ϑ of the line is calculated, based on the calculated resistance R and ParSet3. In the calculating element B13, an estimation of how the temperature will develop with respect to time $\vartheta(t+)$ is made under the assumptions specified in ParSet4. In the calculating element B14, the calculated value of the conductor temperature ϑ and the time function $\vartheta(t+)$ of the estimated temperature are finally compared with a number of limit values that may be time- or temperature-related, specified in ParSet5, and binary alarm signals A1-An are set at the outputs. The measuring unit M1 and all the calculating elements B11-B14 may advantageously be arranged in the same physical calculating unit B1.

Figure 3 shows an embodiment of the invention in the form of a flow chart based on the components in Figure 2. The calculation is started and initiated by reading the parameters in the parameter sets ParSet1 - ParSet5. Thereafter, the measured values U1 and I1 are detected in the measuring unit M1. In the next step B11, the measured values U2, I2 from the other end of the line L1 are read, whereupon the line resistance R is calculated and outputted. After this, the conductor temperature ϑ, is calculated and outputted in the calculating unit B12, whereupon an estimate of the development of the temperature with respect to time ϑ(t+) is determined and outputted in the calculating unit B13. Finally, the calculated temperature ϑ and its estimated time function ϑ(t+) are compared with a number of limit values to provide an alarm on time and temperature criteria.

In a preferred embodiment of the invention, an estimated value of the conductor temperature is updated regularly, for example every second. The calculation is suitably carried out in two stages, where in the first stage (1) the resistance, *R*, is determined as follows:

$$R = \mathrm{Re}\left[\frac{U_1 - U_2}{I_1 + I_{shunt1}}\right] \qquad (1)$$

where

U_1 = the complex voltage at the transmitter end of the line;
U_2 = the complex voltage at the receiver end of the line;
I_1 = the complex current out on the line at the transmitter end;
I_{shunt1} = the complex current component from a shunt contribution at the transmitter end.

Thereafter, the resistivity $\rho(\vartheta)$ of the conductor material, at the temperature deviation, ϑ, is determined from the equation:

$$R(\vartheta)=\rho(\vartheta)\frac{l(\vartheta)}{A(\vartheta)} \qquad (2)$$

where

ϑ = the deviation of the conductor material from the reference temperature;
$\rho(\vartheta)$ = the resistivity of the conductor material at the temperature in question;
$l(\vartheta)$ = the length of the conductor at the temperature in question;
$A(\vartheta)$ = the equivalent area of the conductor at the temperature in question.

For reasonable values of the temperature deviation, equation (2) may be written as follows:

$$R(\vartheta)=(\rho_0+\frac{d\rho}{d\vartheta}\vartheta)\frac{l_0+\frac{dl}{d\vartheta}\vartheta}{A_0+\frac{dA}{d\vartheta}\vartheta} \qquad (3)$$

where
ρ_0 = the resistivity of the conductor material at the reference temperature;
l_0 = the length of the conductor at the reference temperature;
A_0 = the equivalent area of the conductor at the reference temperature.

Equation (3) may now be written as follows:

$$R(\vartheta)=\rho_0\left[1+\left(\frac{1}{\rho_0}\frac{d\rho}{d\vartheta}+\frac{1}{l_0}\frac{dl}{d\vartheta}-\frac{1}{A_0}\frac{dA}{d\vartheta}\right)\vartheta\right]\frac{l_0}{A_0} \qquad (4)$$

Correction for the linear and area expansions, respectively, of the conductor with increased temperature may now be included in the temperature coefficient α of the conductor, which gives:

$$R(\vartheta) = \rho_0 (1 + \alpha\vartheta) \frac{l_0}{A_0} \quad (5)$$

A still better approximation may be obtained by taking into consideration the temperature dependence of the temperature coefficient, which may be of interest if the conductor temperature deviates considerably from the reference temperature. A simple method for determining the relationship between conductor temperature and conductor resistance may be to measure the line resistance at a few different values of the ambient temperature when the current is near zero.

In still another advantageous embodiment of the invention, also the current at the receiver end, I_2, is utilized in the calculation algorithm, in which case a calculation may be made at each conductor end, whereupon, for example, a mean value may be formed.

In yet another embodiment of the invention, compensation is made for the capacitance change between power transmission lines and ground as a result of increased sagging at an increased conductor temperature.

In yet a further embodiment of the invention, corona losses are compensated for.

In a still further advantageous development of the invention, a computer program comprises program instructions that control a computer or a computer process to control or simulate a method for determining the load state of power system components in an electric power system in accordance with the invention.

In an additional advantageous development of the invention, a computer program that controls a computer or a computer process to control or simulate a method for determining the load state of power system components in an electric power system in accordance with the invention is recorded or stored on one or more computer-readable media.

The system comprises members, shown in the figures as flow diagrams and block diagrams. The block diagrams may be conceived both as a signal flow diagram and a block diagram describing a piece of equipment for the system. A function performed in a flow diagram or by a block shown in the block diagram may in applicable parts be implemented by analog and/or digital technique but is advantageously performed as programs in a microprocessor, in a computer program or as a computer program code element performed in a computer or in a computer process. It is to be understood that when the flows and blocks shown in the figure are referred to in a physical embodiment as a device, an apparatus, etc., they are to be conceived as means for achieving a desired function, especially when the function is implemented as software in a microprocessor. Consequently, as the case may be in this case, the expression "signal" may also be interpreted as a value generated by a computer program and also appear in this form only. The blocks are described only as a functional description since these functions may be implemented by a person skilled in the art in a manner known per se.

The above invention has been described with reference to different preferred embodiments. The invention is not, of course, limited to these embodiments but other variants of embodiments are also embraced by the scope of protection of the patent.

CLAIMS

1. A method for determining the load state in a power system component, such as a line, in an electric power system, **characterized** by

- determining the reference temperature for the conductor material,
- determining current and voltage on the line,
- transferring these values to a calculating unit,
- calculating a value for the actual resistance of the line, based on current and voltage values,
- calculating the temperature, and hence the degree of load, of the line based on the above values.

2. A method according to claim 1, **characterized** in that the measurement of values for current and voltage on the line is performed in a time-synchronized manner.

3. A method according to claim 1 and/or claim 2, **characterized** in that said temperature-dependent conductor resistance is calculated based on measuring or calculating current and voltage at at least one of the end points of the power system component.

4. A method according to one or more of the preceding claims, **characterized** in that said temperature-dependent conductor resistance is calculated based on voltage measurement at both end points of the power system component and current measurement at at least one end point.

5. A method according to one or more of the preceding claims, **characterized** in that said calculation of the resistance is compensated for a changed line capacitance to ground following a changed sag.

6. A method according to one or more of the preceding claims, **characterized** in that

said calculation of the resistance is compensated for corona losses.

7. A system for determining the load state in a power system component, such as a line, in an electric power system, **characterized** in that
- means are arranged for determining the reference temperature for the conductor material,
- means are arranged for determining current and voltage on the line,
- means are arranged for transferring these values to a calculating unit,
- means are arranged for calculating a value for the prevailing resistance of the line based on current and voltage values,
- means are arranged for calculating the temperature of the line and hence the degree of load, based on the above values.

8. A system according to claim 7, **characterized** in that
- means are arranged to synchronize the measurement of current and voltage on the line with respect to time.

9. A system according to claim 7 and/or 8, **characterized** in that
- means are arranged to calculate the temperature-dependent conductor resistance based on measurement or calculation of current and voltage at at least one of the end points of the power system component.

10. A method according to one or more of the preceding claims, **characterized** in that
- means are arranged to calculate said temperature-dependent conductor resistance based on voltage measurement at both end points of the power system component and current measurement at at least one end point.

11. A method according to one or more of the preceding claims, **characterized** in that

- means are arranged to compensate for said resistance calculation for a changed line resistance to ground following a changed sag.

12. A method according to one or more of the preceding claims, **characterized** in that
- means are arranged to compensate for said resistance calculation for corona losses.

13. A computer program comprising computer program code for carrying out a method according to any of claims 1-6.

14. A computer-readable medium comprising at least part of the computer program according to claim 13.

15. A computer program according to claim 13 which, at least in part, is transmitted via a network, such as, for example, an intranet or the Internet.

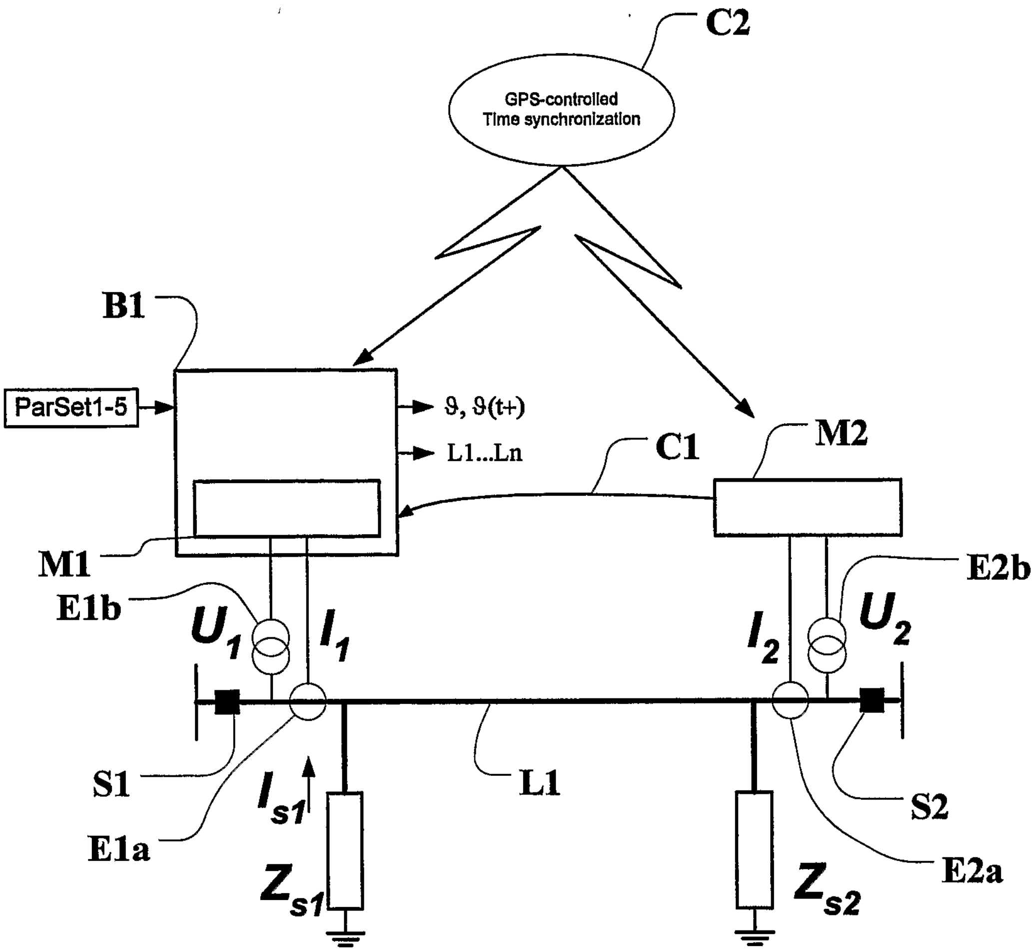
C2
GPS-controlled
Time synchronization
B1
ParSet1-5
ϑ, ϑ(t+)
L1...Ln
C1
M2
M1
E1b
E2b
U_1
I_1
I_2
U_2
S1
L1
S2
I_{s1}
E1a
E2a
Z_{s1}
Z_{s2}

Figure 1

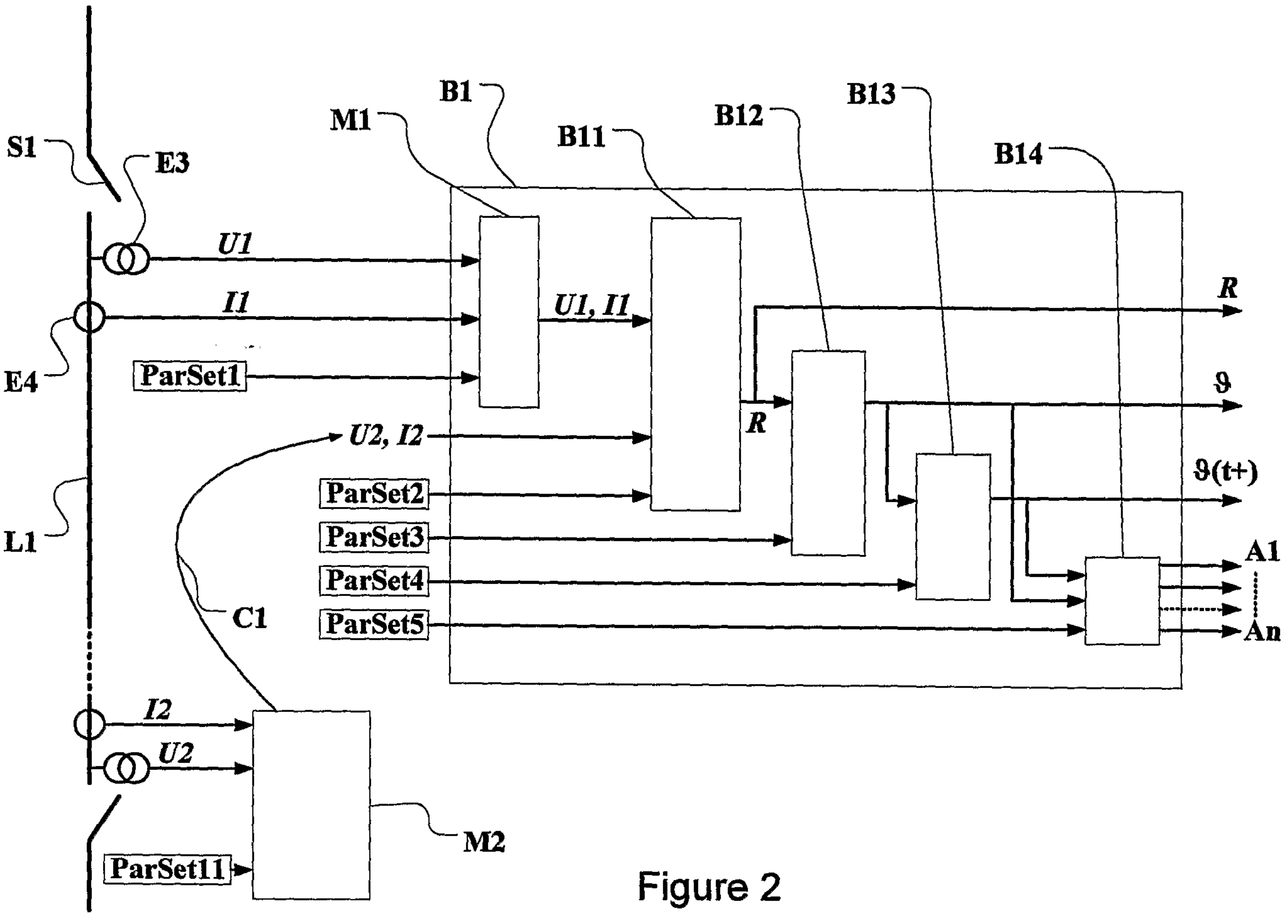
B1
M1
B11
B12
B13
B14
S1
E3
U1
I1
U1, I1
R
E4
ParSet1
ϑ
R
U2, I2
ϑ(t+)
ParSet2
L1
ParSet3
A1
ParSet4
C1
ParSet5
An
I2
U2
M2
ParSet11

Figure 2

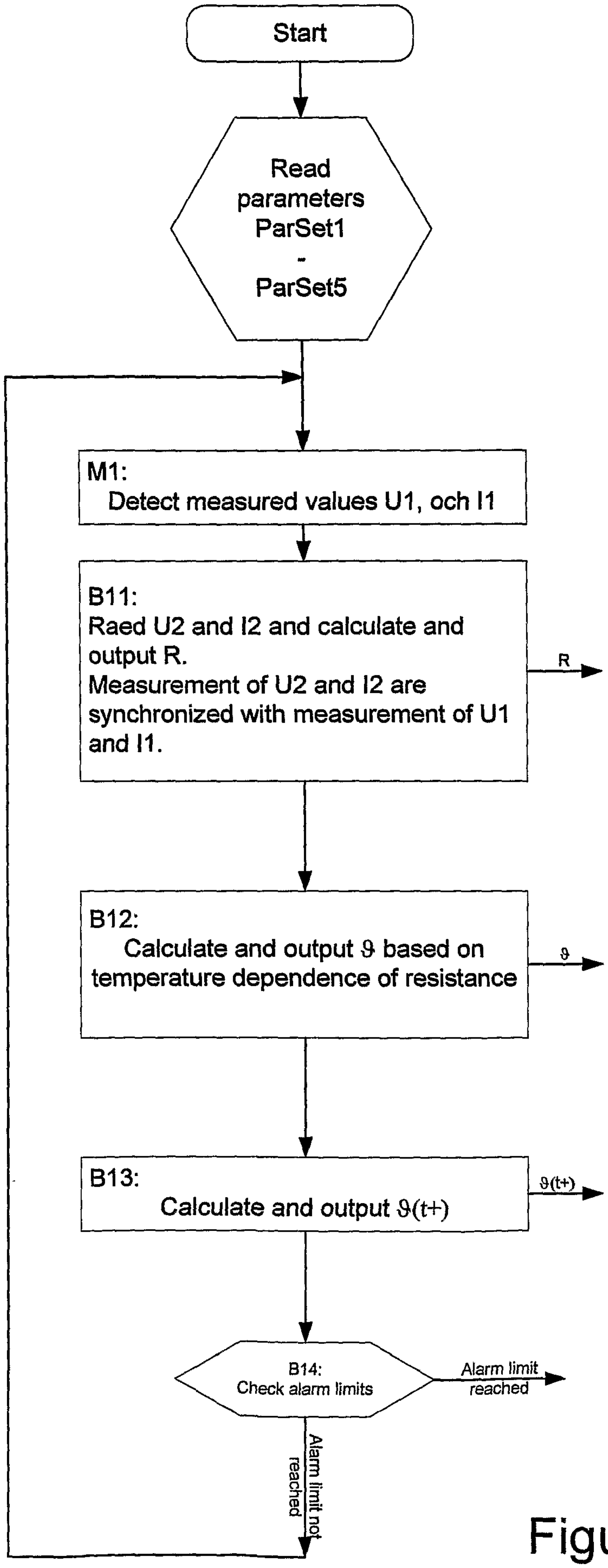
Start
Read parameters ParSet1 - ParSet5
M1:
Detect measured values U1, och I1
B11:
Raed U2 and I2 and calculate and output R.
Measurement of U2 and I2 are synchronized with measurement of U1 and I1.
R
B12:
Calculate and output ϑ based on temperature dependence of resistance
ϑ
B13:
Calculate and output ϑ(t+)
ϑ(t+)
B14:
Check alarm limits
Alarm limit reached
Alarm limit not reached

Figure 3

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE2005/002011

A. CLASSIFICATION OF SUBJECT MATTER

IPC: see extra sheet

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC: G01R, H02H

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

SE,DK,FI,NO classes as above

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

EPO-INTERNAL, WPI DATA, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 1324454 A1 (ABB SCHWEIZ AG), 2 July 2003 (02.07.2003), figure 1, abstract	1-5,7-11, 13-15
Y		6,12
	--	
X	Extended Version with Modern Physics, 9th Edition 1996, "University Physics": Hugh D Young et al. pages 803-808, 826 83D	1-5,7-11
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[X] Further documents are listed in the continuation of Box C. [X] See patent family annex.

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"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance: the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance: the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
3 April 2006	06-04-2006
Name and mailing address of the ISA/ Swedish Patent Office Box 5055, S-102 42 STOCKHOLM Facsimile No. +46 8 666 02 86	Authorized officer Sture Elnäs/MN Telephone No. +46 8 782 25 00

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE2005/002011

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	DATABASE WPI Week 199113 Derwent Publications Ltd., London, GB; Class S01, AN 1991-093552 & SU1582144 A (AZERB POWER GEN RES), 30 July 1990 (1990-07-30) abstract	6,12

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H02H 6/00 (2006.01)
H02H 7/26 (2006.01)

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Paper copies can be ordered at a cost of 50 SEK per copy from PRV InterPat (telephone number 08-782 28 85).

Cited literature, if any, will be enclosed in paper form.

EP	1324454	A1	02/07/2003	AU	2002366845	A	00/00/0000
				BR	0215234	A	16/11/2004
				CA	2470630	A	03/07/2003
				US	20050222808	A	06/10/2005
				WO	03055028	A	03/07/2003
