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(54) Title: A SYSTEM FOR GROUND FAULT DETECTION IN A GENERATOR

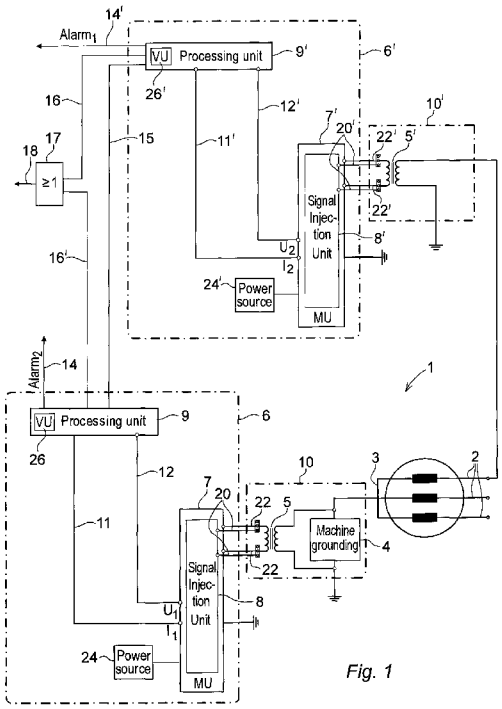



Fig. 1

(57) Abstract: The present invention relates to a ground fault detection system for a generator (1 ) in a power system, wherein the generator comprises at least one electrical circuit (10, 10'). The ground fault detection system comprises a first signal injection unit (8) configured to inject a first test signal ($t_1$) at a first frequency ($f_1$) into the electrical circuit (10), a first measuring unit (7) configured to measure electrical quantities ($U_1$, $I_1$) in the electrical circuit resulting from the first test signal, a first processing unit (9) configured to receive said measured electrical quantities resulting from the first test signal and calculate a first electrical parameter ($Z_1$) based on the measured electrical quantities in order to determine if there is a ground fault, a second signal injection unit (8') configured to inject a second test signal ($t_2$) at a second frequency ($f_2$) into the electrical circuit (10'), a second measuring unit (7') configured to measure electrical quantities ($U_2$, $I_2$) in the electrical circuit resulting from the second test signal, and a second processing unit (9') configured to receive said measured electrical quantities resulting ($U_2$, $I_2$) from the second test signal and calculate a second electrical parameter ($Z_2$) based on the measured electrical quantities in order to determine if there is a ground fault. The invention is characterized by the first processing unit further configured to send the first calculated electrical parameter to the second processing unit, the second processing unit configured, upon receiving the first calculated electrical parameter sent by the first processing unit, to compare the first calculated electrical parameter and the second calculated electrical parameter to determine if there is a ground fault, and if the deviation exceeds a selected criterion an alarm (*Alarm*$_1$) may arise, equally, the second processing unit further configured to send the second calculated electrical parameter to the first processing unit, and the first processing unit configured, upon receiving the second calculated electrical parameter sent by the second processing unit, to compare the first calculated electrical parameter and the second calculated electrical parameter to determine whether there is a ground fault, and if the deviation exceeds a selected criterion an alarm (*Alarm*$_2$) may arise.

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# A SYSTEM FOR GROUND FAULT DETECTION IN A GENERATOR

## FIELD OF THE INVENTION

The present invention relates to a ground fault detection system for a generator of a power system.

## PRIOR ART

Ground faults in generator stator windings pose a considerable danger for the proper operation of the generator. They are the most frequent causes of damage to the stator winding of the generator and the direct cause of phase-to-phase faults. There are two main categories of ground faults, those that originate from mechanical damage and those that are caused by failure of the insulation material.

Standards and recommendations show that generator stator protection system should detect ground faults at any point of the generator stator winding, including the generator neutral. Additionally to minimize the possibility of improper operation of the generator ground-fault protection system, and ensure 100% protection for the generator magnetic circuit as well as and maximum protection redundancy, one should use protection systems based on different exciting criteria.

Ground faults are detected in power generators by injection of an off-nominal frequency and measuring the impedance to ground. However, present systems are forced to use a low frequency which is related to the nominal frequency, in order to suppress the nominal frequency effectively. The chosen frequency is affected by the design details and cannot be changed. Therefore, it is impossible to install two such systems from the same manufacturer to achieve redundancy, which is desired in important installations, like nuclear power plants.

In a PCT patent application with the international publication number WO2008/077955, an arrangement for determining an electrical feature for an electrical device is described. The arrangement comprises a signal injection unit for injecting a test signal at an off-nominal frequency into an electrical circuit of the electrical device, a signal conversion unit for measuring electrical quantities from the injected test signal, and a processing device for receiving the measured electrical quantities in order to determine the electrical feature. Such an electrical feature can, for example, be used for detecting ground faults for a generator. Redundancy for determining electrical features of the electrical device can be achieved by applying two arrangements, a first and second arrangement. A first signal injection unit of the first arrangement injects a first test signal at a first off-nominal frequency into a first electrical circuit of the device and a second signal injection unit injects a second test signal at a second off-nominal frequency into a second electrical circuit of the device. A first and second processing device calculates the electrical features based on the measured electrical quantities received respectively from a first and second signal conversion unit. An output signal is determined based on a first output signal generated by the first processing unit and a second output signal generated by the second processing. Such an output signal may be an important decision, for example an output trip signal used to initialize the disconnection of a generator from its power supply. However, such a decision may be a wrong decision due to a failure of one of the arrangements. For example, the first arrangement itself may have a ground fault or a power-supplying fault, which affects the first output signal, thereby the final output signal. In many applications a false output signal results in undesired consequence, for example an unnecessary shutdown for a nuclear power plant or, on the other hand, serious damage to the electrical device because of a ground fault. Therefore, a reliable redundancy is desired.

## OBJECTS AND SUMMARY OF THE INVENTION

The object of the present invention is to provide a reliable redundant ground fault detection system for a generator in a power system.

This object is achieved by a ground fault detection system as defined in claim 1.

Such a ground fault detection system comprises:

- a first signal injection unit configured to inject a first test signal at a first frequency into the electrical circuit,
- a first measuring unit configured to measure electrical quantities in the electrical circuit resulting from the first test signal,
- a first processing unit configured to receive said measured electrical quantities resulting from the first test signal and calculate a first electrical parameter based on the measured electrical quantities in order to determine if there is a ground fault,
- a second signal injection unit configured to inject a second test signal at a second frequency into the electrical circuit,
- a second measuring unit configured to measure electrical quantities in the electrical circuit resulting from the second test signal, and
- a second processing unit configured to receive said measured electrical quantities resulting from the second test signal and calculate a second electrical parameter based on the measured electrical quantities in order to determine if there is a ground fault.

The invention is characterized by,

- the first processing unit further configured to send the first calculated electrical parameter to the second processing unit,
- the second processing unit further configured, upon receiving the first calculated electrical parameter sent by the first processing unit, to compare the first calculated electrical parameter and the second calculated electrical parameter to determine if there is a ground fault, and if the deviation exceeds a selected criterion an alarm may arise,
- equally, the second processing unit further configured to send the second calculated electrical parameter to the first processing unit, and
- the first processing unit further configured, upon receiving the second calculated electrical parameter sent by the second processing unit, to compare the first calculated electrical parameter and the second calcu-

lated electrical parameter to determine whether there is a ground fault, and if the deviation exceeds a selected criterion an alarm may arise.

In the following each set of a signal injection unit, a measuring unit and a processing unit is called a ground fault detection device. The redundancy is achieved by applying two ground fault detection devices.

Thanks to the fact that the invention enables the exchange of the calculated electrical parameters between the first and second ground fault detection devices, which therefore enables these two separate ground fault detection devices to monitor to each other, and determination of a ground fault is based on both the first and second calculated electrical parameters, a higher-level safety and a highly reliable redundancy of the system are achieved.

For example, upon receiving the second calculated electrical parameter sent by the second processing unit, the first processing unit compares the first and second calculated electrical parameters to determine whether there is a ground fault, and if the deviation between the first and second calculated electrical parameters exceeds a selected criterion an alarm may arise to indicate that one of the ground fault detection devices may have a problem. Thus, the invention improves the reliability of the redundancy system.

According to an embodiment of the invention, the measured electrical quantities are voltage or current, and the first and second calculated electrical parameters are impedances. When the test signals are injected into the electrical circuit, voltage and current are measured and an impedance of the electrical circuit is calculated based on the measured voltage or current. The calculated impedances are used to determine if there is a ground fault.

According to an embodiment of the invention, the injected first and second frequencies are different off-nominal frequencies. The advantage of selecting an off-nominal frequency is that it can be clearly distinguished from

any other harmonic present in the generator. This is particularly useful in case that the first or the second ground fault detection device is, for example, an AC device.

Selecting different off-nominal frequencies for injected test signals guarantees redundancy of the system. It may happen that a freely selected frequency at which a test signal is injected to the electrical circuit of the generator is disturbed by starting other devices close to the generator, for example by starting a pump located close to the generator. As a consequence, the measuring of the electrical qualities will be affected, which eventually affects the detection of ground faults. For example, the first signal injection unit injects the first test signal into the electrical circuit of the generator at the first off-nominal frequency 135 Hz, and at the same time the second signal injection unit injects the second test signal at the second off-nominal frequency 235 Hz. If the first injected test signal is disturbed by starting a pump close to the generator, the electrical quantities of the second test signal will still be measured properly. The measured electrical quantities will then be processed by the second processing unit in order to calculate the second electrical parameter based on the measured electrical quantities to determine if there is a ground fault, and therefore the redundancy of the detection is achieved.

According to an embodiment of the invention, each of the processing units further comprises a voting unit configured to determine whether there is a ground fault based on a selected voting principle and a statistical analysis which is based on the first and the second calculated electrical parameters.

According to an embodiment of the invention, the selected voting principle is any of 1 out of 2, 2 out of 2, or 2 out of 3. Any other voting principles may also be applicable.

According to an embodiment of the invention, the first signal injection unit is configured to inject the first test signal into the electrical circuit through a first injection path and the second signal injection unit is configured to

inject the second test signal into the electrical circuit through another, a second injection path different from the first injection path. For example, the first signal injection unit injects the first test signal into the electrical circuit at a neutral point of the generator and the second signal injection unit injects the second test signal at the terminal of the generator. Another example is that the first signal injection unit injects the first test signal into the electrical circuit at a neutral point of voltage transformer connected between the generator neutral and ground, and the second signal injection unit injects the second test signal at the terminal of the generator. It is advantageous that the test signals are injected into the electrical circuit of the generators through two separate paths; since this enables full detection of ground faults.

According to an embodiment of the invention, each of the signal injection units has its own power supplying means. Separate power supplying means prevent the ground fault detection devices from being put out of function at the same time due to failure of a power supply when only one power supplying means is used for both devices.

According to an embodiment of the invention, a communication channel is established between the processing units to enable the processing units to send measured electrical quantities to each other.

According to an embodiment of the invention, the communication channel is based on IEC61850-8-1 or IEC61850-8-2 Interbay communication or IEC61850-9-1 or IEC61850-9-2 process bus level or IEC61850-9-2 GOOSE. The advantage of using communication protocols defined in IEC61850 standard is an add-value for users since then each ground fault detection device may be configured to exchange data with other devices which also support the IEC61850 communication standard, no matter if those devices are manufactured by one manufactory or different manufactories.

According to an embodiment of the invention, the generator comprises a stator and a rotor, the stator comprising an electrical circuit and the rotor

comprising an electrical circuit, whereby the electrical circuit is any of the electrical circuit of the stator or the electrical circuit of the rotor. By arranging the ground fault detection devices for stator and rotor, respectively, the invention provides the ground fault protection with redundancy for both the stator and the rotor of the generator.

## BRIEF DESCRIPTION OF THE DRAWINGS

The invention will now be explained more closely by the description of different embodiments of the invention and with reference to the appended figure.

Figure 1 shows a schematic diagram of an example of a ground fault detection system connected to a generator, wherein the ground fault detection system comprises two redundant ground fault detection devices for detecting ground faults in the generator, according to the invention.

## DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS OF THE INVENTION

Figure 1 shows a schematic diagram of an example of a ground fault detection system connected to a generator 1. The generator 1 is grounded via a machine grounding unit 4.

The generator 1 is a three-phase generator comprising stator windings 2 and rotor windings which are not shown in the figure. The stator windings 2 are wye connected and a neutral 3 of the generator is grounded via the machine grounding unit 4. A first and second voltage transformer 5, 5' is connected to the generator. A main function of voltage transformers is to transform voltages in the stator grounding circuit down to a measurable level. Instead of the voltage transformer 5, an open delta transformer may be used. The combination of the machine grounding unit 4 and the voltage transformer 5 is regarded in the following as a first electric circuit 10 being

connected with the stator windings 2 and the voltage transformer 5' is regarded as a second electrical circuit 10'.

The ground fault detection system comprises two redundant ground fault detection devices, a first 6 and second 6' ground fault detection device for detecting ground faults in the generator, a communication channel 15 for exchanging data between the two ground fault detection devices 6 and 6', and a logic unit 17 for determining if there is a ground fault based on outputs from the first and second ground fault detection devices.

Each 6, 6' of the ground fault detection devices comprises a measuring unit 7, 7', a processing unit 9, 9', a first analog transmission channel 11, 11' and a second analog transmission channel 12, 12', and a power source 24, 24'. Each of the measuring units further comprises a signal injection unit 8, 8' and a power source 24, 24'.

The first signal injection unit 8 is configured to inject a first test signal $t_1$ at a first main frequency $f_1$ via the connection 20 to the low voltage side of the first electric circuit 10 connected to the stator winding 2. The signals can in the simplest case be sinusoidal signals, i.e. the respective main frequency $f_1$ is the only frequency contained in the signal. But they can also have any other suitable shape comprising multiple frequencies with one dominant frequency $f_1$, as for example a rectangular pulse signal. The main frequencies $f_1$ are chosen to be asynchronous to any other harmonic present in the generator 1, so that the main frequencies $f_1$ are distinguishable and can be singled out from the spectrum of signals measurable in the stator windings 2. The second signal injection unit 8' is configured to inject a second test signal $t_2$ at a second main frequency $f_2$ via the connection 20' to the second electric circuit 10' connected to the terminal side of generator, which means that a different injection path is selected for injecting the second test signal $t_2$.

The first measuring unit 7 is connected via the connecting lines 22 to the first electric circuit 10 and the measuring unit 7' is connected via the connecting line 22' to the second electric circuit 10'. The response of the sta-

tor windings 2 to the first test signal $t_1$ and the response of the terminal of the generator to the second test signal $t_2$ are respectively measured by the measuring unit 7 and the measuring unit 7'. The corresponding analog signals representing the measured voltage and current of the responses are outputs as voltage measurement $U_1$, $U_2$ and current measurement $I_1$, $I_2$ measured by the first measuring unit 7 and the second measuring unit 7', respectively.

The first 11, 11' and second 12, 12' analog transmission channels are the connections lines between the measuring unit 7, 7' and the processing unit 9, 9', and configured to transmit measurements $I_1$, $U_1$, $I_2$, $U_2$ from the measuring unit 7, 7' to the processing unit 9, 9'.

The measurements $I_1$ and $U_1$ are then analyzed and processed by the processing unit 9 to single out the first frequency $f_1$, thereby obtaining phasors of the first current and voltage at the frequency $f_1$: $I_1(f_1)$, $U_1(f_1)$. From the first current and voltage phasors, $I_1(f_1)$ and $U_1(f_1)$, a first electrical parameter, for example a first impedance $Z_1$, is calculated, which represents the impedance of the stator winding 2. The first impedance is used by the first processing unit 9 for detection of ground faults by comparing it with a predetermined value. Accordingly, the same procedures are performed by the second processing unit 9', and eventually a second electrical parameter or second impedance $Z_2$, is calculated and compared with a predefined value.

The impedance $Z_1$ or $Z_2$ which has a smaller real part than the predetermined value indicates a ground fault of the winding.

To be able to determine ground faults more precisely, each 9, 9' of the processing units further comprises a voting unit 26, 26' configured to determine whether there is a ground fault based on a selected voting principle and a statistical analysis. Such a voting principle is any of 1 out of 2, 2 out of 2, or 2 out of 3. If there is a ground fault, a trip signal 16, 16' is generated respectively. The trip signals are then OR-connected to a logic unit 17 which generates a final output trip signal 18 to initiate a particular

action, for example the disconnection of the generator from its power supply.

The communication channel 15 is established between the first 9 and second 9' processing units to enable the exchanges of the calculated electrical parameters, therefore enabling mutual monitoring between the two devices. For example, upon receiving the second calculated electrical parameter sent by the second processing unit, the first processing unit compares the first calculated electrical parameter and the second calculated electrical parameter to determine whether there is a ground fault, and an alarm $alarm_2$ may then be initiated by the processing units 9 to indicate that a selected criterion has been exceeded by a deviation between the first calculated impedance $Z_1$ and the second calculated impedance $Z_2$, which improves reliability of the redundancy system.

Communication protocols supported by the communication channel 15 may be based on or compatible with IEC61850-8-1 or IEC61850-8-2 Interbay communication or IEC61850-9-1 or IEC61850-9-2 process bus level or IEC61850-9-2 GOOSE.

The first 7 and second 7' measuring units have their own power sources 24 and 24', respectively, to prevent ground fault detection devices from being put out of function at the same time due to the failure of a power supplying source when only one power supplying source is used for both devices.

The invention can also be applied to rotor windings of the generator for detection ground faults. In fact, the invention can be applied to both stator and rotor windings of the generator for detection of ground faults simultaneously.

## CLAIMS

1. A ground fault detection system for a generator (1) in a power system, wherein the generator comprises at least one electrical circuit (10, 10'), the ground fault detection system comprising:

- a first signal injection unit (8) configured to inject a first test signal ($t_1$) at a first frequency ($f_1$) into the electrical circuit (10),
- a first measuring unit (7) configured to measure electrical quantities ($U_1$, $I_1$) in the electrical circuit resulting from the first test signal,
- a first processing unit (9) configured to receive said measured electrical quantities resulting from the first test signal and calculate a first electrical parameter ($Z_1$) based on the measured electrical quantities in order to determine if there is a ground fault,
- a second signal injection unit (8') configured to inject a second test signal ($t_2$) at a second frequency ($f_2$) into the electrical circuit (10'),
- a second measuring unit (7') configured to measure electrical quantities ($U_2$, $I_2$) in the electrical circuit resulting from the second test signal, and
- a second processing unit (9') configured to receive said measured electrical quantities resulting ($U_2$, $I_2$) from the second test signal and calculate a second electrical parameter ($Z_2$) based on the measured electrical quantities in order to determine if there is a ground fault.

**characterized** in that:

- the first processing unit is further configured to send the first calculated electrical parameter to the second processing unit,
- the second processing unit is configured, upon receiving the first calculated electrical parameter sent by the first processing unit, to compare the first calculated electrical parameter and the second calculated electrical parameter to determine if there is a ground fault, and if the deviation exceeds a selected criterion an alarm ($Alarm_1$) may arise,
- equally, the second processing unit is further configured to send the second calculated electrical parameter to the first processing unit, and
- the first processing unit is configured, upon receiving the second calculated electrical parameter sent by the second processing unit, to compare the first calculated electrical parameter and the second cal-

culated electrical parameter to determine whether there is a ground fault, and if the deviation exceeds a selected criterion an alarm ($Alarm_2$) may arise.

2. The ground fault detection system according to claim 1, wherein said measured electrical quantities are voltage or current, and said first and second calculated electrical parameters are impedances.

3. The ground fault detection system according to claim 1, wherein said injected first frequency and second frequency are different off-nominal frequencies.

4. The ground fault detection system according to claim 1, wherein each of processing units further comprises a voting unit configured to determine whether there is a ground fault based on a selected voting principle and a statistical analysis which is based on the first and second calculated electrical parameters.

5. The ground fault detection system according to claim 4, wherein said selected voting principle is any of 1 out of 2, 2 out of 2, or 2 out of 3.

6. The ground fault detection system according to claim 1, wherein the first signal injection unit is configured to inject the first test signal into the electrical circuit through a first injection path and the second signal injection unit is configured to inject the second test signal into the electrical circuit through another, a second different injection path.

7. The ground fault detection system according to claim 1, wherein each of said injection units has its own power supplying means.

8. The ground fault detection system according to claim 1, wherein a communication channel is established between the processing units to enable the processing units to send measured electrical quantities to each other.

9. The ground fault detection system according to claim 8, wherein the communication channel is based on IEC61850-8-1 or IEC61850-8-2 Inter-bay communication or IEC61850-9-1 or IEC61850-9-2 process bus level or IEC61850-9-2 GOOSE.

10. The ground fault detection system according to claim 1, wherein the generator comprises a stator and a rotor, the stator comprising an electrical circuit and the rotor comprising an electrical circuit, said electrical circuit being any of the electrical circuit of the stator or the electrical circuit of the rotor.

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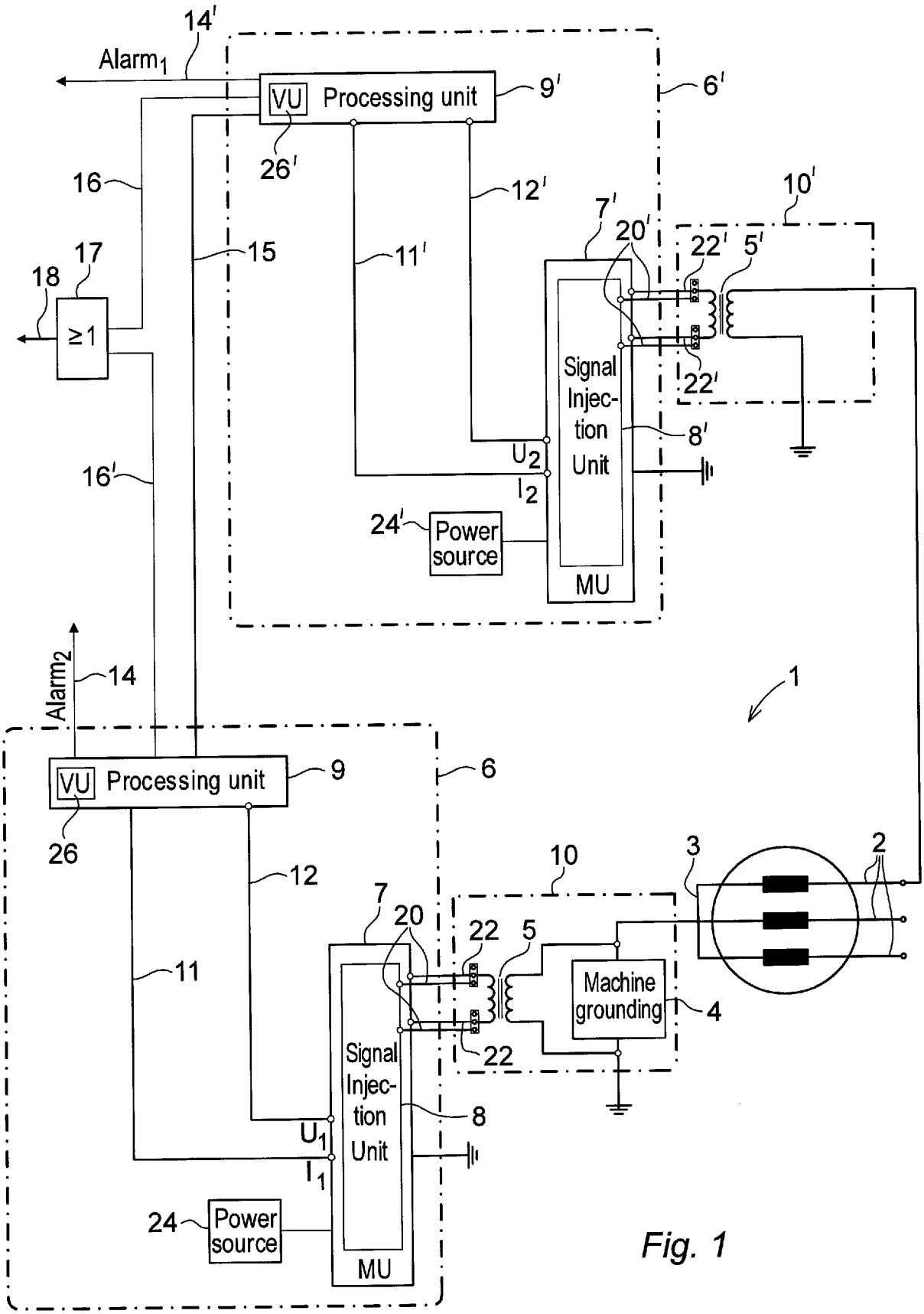

14'
Alarm1
VU Processing unit
9'
6'
26'
16
12'
10'
7'
20'
22'
5'
17
18
15
11'
≥1
Signal Injec- tion Unit
8'
22'
U2
I2
16'
24'
Power source
MU
1
Alarm2
14
VU Processing unit
9
6
26
12
10
3
2
7
20
22
5
11
Machine grounding
4
22
Signal Injec- tion Unit
8
U1
I1
24
Power source
MU

Fig. 1

# INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2009/066027

**A. CLASSIFICATION OF SUBJECT MATTER**
INV. G01R27/18 G01R31/02 G01R31/06 G01R31/34 G05B9/03

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)
G01R G05B

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

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

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|---|---|---|
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[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

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| Date of the actual completion of the international search | Date of mailing of the international search report |
|---|---|
| 19 March 2010 | 25/03/2010 |

| Name and mailing address of the ISA/ | Authorized officer |
|---|---|
| European Patent Office, P.B. 5818 Patentlaan 2<br>NL - 2280 HV Rijswijk<br>Tel. (+31-70) 340-2040,<br>Fax: (+31-70) 340-3016 | Koll, Hermann |

Form PCT/ISA/210 (second sheet) (April 2005)

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Information on patent family members

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